Three essays examining conceptual change and understanding across science disciplines with three different learner populations

Dissertation

Presented in Partial Fulfillment of the Requirements for the Degree Doctor of Philosophy in the Graduate School of The Ohio State University

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Graduate Program in Education: Teaching and Learning

The Ohio State University
2015

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Abstract

The following dissertation details three different research studies centered on conceptual change and conceptual understanding as a theoretical framework for research. The three studies span across age groups and science content areas. Study one details young children’s understanding of the day and night skies both before and after a play-based instructional intervention. The preschool setting can capitalize on young children’s interests in science explorations and be highly engaging for young children (French, 2004). Play is considered as an integral part of early childhood curricula, and has been receiving much attention in the last decade, yet there is a lack of evidence about the effectiveness of play as a pedagogical tool for young learners in general and more specifically for children’s learning of science concepts. Study one layers play pedagogy and the theoretical framework of conceptual change theory.

Study two seeks to examine conceptual understandings and changes after providing in-service teachers with an inquiry based professional development based on space science concepts. Four early childhood teachers participated in 12 hours of an inquiry-based professional development (PD) built on Physics by Inquiry (McDermott, 1996). Two of these teachers were followed into their classrooms for researchers to
observe and gain understanding of the efficacy of their instructional implementation with preschool children.

Study three aims to perform the first implementation of the English version of The Nature of Solutions and Solubility—Diagnostic Instrument (NSS–DI Eng) with college students enrolled in a first year chemistry course. This two-tiered instrument was designed to assess students’ understanding of solution chemistry concepts that are important on their own but are also foundational to more advanced chemistry concepts. To evaluate the reliability and the discriminatory power of this assessment tool, statistical tests were used focusing on both item analysis (item difficulty index, discrimination index, point-biserial coefficient) and whole-test statistics (Cronbach’s alpha and Ferguson’s delta). Results indicate that the English version of the NSS-DI is an acceptable and reliable instrument for assessing student conceptions of solution chemistry concepts but may benefit from minor changes.
Dedication

This work is dedicated to Brant and Lincoln and my nieces and nephews who I hold near to my heart as I work with new teachers, with the prayer that you will be blessed with teachers who will help you bloom into your own creative selves. Yeats comments, “education is not the filling of a pail, but the lighting of a fire”. I pray each of your educations will not be that of mere conformity, but of the igniting of something unique within each of you.
Acknowledgements

This dissertation and doctoral degree would not have been possible without the guidance, love and support of countless individuals. These mere few pages are not enough to express the full entirety of my gratitude for the love, patience and support from many notable individuals.

**Faith:** First and foremost, “with God all things are possible.”

**Committee Members:** Thank you to my committee members who have given their unwavering guidance and support throughout this process. To Dr. Lin Ding, my advisor, thank you for taking me on so late in my graduate studies. I appreciate all the time you have committed to helping me, your statistics savvy and for your straightforward feedback. I am so very grateful, your commitment to all of your students, not just your advisees is apparent to all whom you work with. To Dr. Leslie Moore, thank you for always having a sage, kind and often humorous word. Your wisdom into the professoriate will serve me well in life and my next ventures. I hope I may find my own ‘linguist ladies’ and strive to live an ‘acca-amazing’ life. Your prolific writing leaves me in awe and I am grateful for having the chance to write with you and for your feedback on this dissertation. It is better from your touch. To Dr. Larry Krissek who offered his guidance and advice so generously. Your wise words in difficult times kept me moving forward. I’m quite sure my mental capacities would not be (as) in tact had it not been for the hours you spent counseling me. Thank you for your willingness to support me and for your commitment to science education and your students’ success. Finally, to Dr. Kathy Cabe Trundle, the advisor who got me started on this amazing path and helped me progress faster than I could have imagined. I can only hope to live up to your commitment to teacher education and science education research. Thank you for your mentorship, and for the high standards you set. You have made me a better student, educator, writer, researcher and scholar.

**Aspire Family:** You are my people, I would not have succeeded with out your encouragement and wisdom. I am the luckiest GA to have had this fabulous appointment for three years. I am a better teacher-educator for having been a part of this transformative work. Dr. Sandy Stroot, thank you for believing in me so fiercely and for providing a real-life apprenticeship model at this level. Through my appointment, you have guided me in the ways of research, scholarship, presenting and writing, all while smiling and showing me videos of dancing horses. You fought for me and picked me up more times than we could count on our combined fingers. You inspire me daily. Dr. Peggy Kastens, you are
always ready with a kind word, advice and a smile. Your encouragement (and practical scheduling practices) got the words of this dissertation out of my head and onto paper! Dr. Patti Brosnan, thank you for always smiling regardless of what mess I pulled you into. Thank you for being my voice of reason and for the numerous ‘urgent’ phone calls. Marguerethe J., you’re my link to the ‘real’ world, you kept me grounded and my feet in schools; which I so greatly needed. Thank you for your humor and wit along the way, they’ve made this so much more enjoyable. Kerry, your work is grand and needed. I’ve enjoyed watching you work your magic with teachers and students over the last three years. I have no doubts you will make big impacts through your work in redefining interdisciplinarity, it’s time! This group has been a family, we’ve cried, argued, ate, drank, laughed, teased, traveled, worked and celebrated. Aspire has been a gift and I’m blessed to have each of you in my life.

**OSU faculty/staff:** To the education professors I had while completing my doctoral degree (e.g., Dr. D. Bloome, Dr. K. Irving, Dr. J. Nespor, Dr. Tracey Stuckey-Mickel, and Dr. M. Rhoades) who provided exceptional feedback and instruction/direction. To the many staff members who helped me with my endless questions, I thank you from the bottom of my heart. You deserve a medal for your patience! Cesar S. and Janell J., thank you for seeing that I stayed on track and for giving the numerous interruptions I provided in your days. Jackie S., thank you for always making sure I had a paycheck coming, health insurance and keys! Those three issues weigh heavy on a GRA’s mind, thank you so much for your help!

Dr. Teddy Chao, working with you this year at WP has made lasting impacts on my educational experience. I have learned so much by watching your interactions with learners of all ages, as well as, listening and absorbing your passion for equity education. Thank you for believing in me and allowing me to be a part of your empowering work with young children.

**Family:** Thank you to my family for the many years of quiet support, guidance, and patience while on this crazy path. To my children, Brant and Lincoln, your smiles and giggles kept me going and were the “chi” to my day, everyday.

No words can express the appreciation I have for my mother (Sharon) who has always set a positive example through hard work and determination. To my brothers (Derrick and Kent) who have always believed in my capabilities and kept me grounded through lots of teasing. To my dad who always recognized my talents, believed in me and led me to believe I could do anything. Thank you to both of my parents for always placing a high value on education.

To Milt, Sherry, Karen and Gene, thank you for believing in me and for all of the love you share with your grandchildren. Your love for family has helped pave this path.

**Primary and secondary teachers:** To all of the great teachers I had while Lexington Local Schools. Especially to Mr. Todd Korbas, who was lucky/unfortunate enough to
have a 15 year old me in his class everyday for two back-to-back periods. It was during this time where I first became inspired by STEM from his teaching excellence. Twenty plus years later, he is still my gold standard. Those afternoons in tenth grade have stuck with me through my own years of teaching and will go forward as I hope to inspire the next generation of teachers. Thank you for being my spark, I am forever indebted.

Todd Alles, thank you for believing in me and my teaching abilities. Your dedication to both intellectual and character education has made lasting impacts on me and the directions I’ve taken. Your unwavering encouragement helped me believe this was all possible.

Classmates and friends: Thank you to Jamie Schiff, Heather Miller, Kate Mollohan and Amanda Roble friends and brilliant colleagues, who I have had the great fortune of working with for the last four years. Being a part of this group has kept me going. Thanks for the laughs, dinners, lunches, drinks and sharing this crazy journey together.

Shannon Lorenz Morgan, who else has a bestie from the age of 10 to cheer them on through this? You believed in me when I didn’t. Your friendship is an ongoing blessing in my life, I love you.

To my Ya-Yas, redefining girl culture starts here, with smart, courageous, supportive groups of women pushing each other to reach big and picking each other up when we fall. I love you guys so much, thanks for all the love, humor and support along the way.

Last but NEVER least: To Travis, my husband, your adventurous spirit and undying support made this all possible. You saw this path long before I did, I’m so lucky to have such a wonderful partner who went to all ends to support me and this work. Through this journey, I feel that we both learned heaps about what is important and strengthened our commitment and determination to each other and to always live life to the fullest. I love you more and more each day.
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Chapter 1

Background

The Conceptual Change Model of learning is one of the most prominent and researched theories in science education over the last 35 years. Conceptual change learning theory indicates knowledge is individually constructed and influenced by the learners’ prior knowledge, experiences, social and cultural contexts of the learning environment (Driver & Oldham, 1986; Hewson & Hewson, 1988; Strike & Posner, 1992). This learning process often results in the construction of knowledge that is in conflict with scientifically accepted conceptions. These alternative conceptions (sometimes labeled misconceptions) can be persistent and difficult to change through instruction, and can pose obstacles to students’ further conceptual development (Hewson & Hewson, 1984). From the perspective of the individual, their conceptions, while not in agreement with scientific norms, are practical and useful to their world, experiences and understandings. Purposeful science instruction aspires to restructure or reorganize, or students’ alternative conceptions as needed to accommodate scientifically accepted understandings (Smith, Blakeslee, & Anderson, 1993).

Teaching and Learning Science

Teachers must be aware of the original conceptions students hold, as these will influence the ways in which they interact with new content (Hewson, 1982). It is not enough for teachers to acknowledge students come to instruction with differing naïve
conceptions; teachers need to take responsibility for engaging students and designing instruction that is likely to facilitate student conceptual change (Hewson, 1981). Conceptual change for science learning provides evidence for seeing the schooled science learning experience as a gradual and long-term modification of naïve understandings stemming from everyday experiences. Furthermore, the evidence points to the complex social contexts in which this learning takes place. Instruction for conceptual change must thus promote not only the construction of new explanations and theories but also new ways of learning, reasoning and thinking. Conceptual change cannot be accomplished without significant socio-cultural supports.

**Theoretical foundations**

Constructivism has three foundational characteristics: 1. learning is an active process, 2. students construct their knowledge by means of their pre-existing one, 3. learner is responsible from his/her own learning (Freedman, 1998). The field has been evolving starting with Piaget, and then incorporating viewpoints from Dewey and Vygotsky. Vygotsky brings the spotlight to the social-cultural aspects of the construction of knowledge by emphasizing the functions of social process in learning. He suggests new concept knowledge is first experienced socially by children and after time and exposure can then become psychological (Vygotsky, 1978). His implications for instructional design promotes hands-on manipulation, coordinated use of group learning and use of materials. His ideas highlight that child development is the result of interactions between children and their social environment. These interactions involve people (e.g. parents, teachers, peers and siblings) as well as cultural artifacts, such as
books, toys, repurposed objects (e.g. empty boxes) as well as culturally specific traditions in which a child participates in the classroom, playground or at home. Children are active partners and meaning makers in all of these interactions, as they are constructing knowledge, honing new skills, and forming attitudes. These actions are not simply children mirroring the world around them, rather, this is the heart of constructing knowledge through experience and tools. Given the social nature of this outlook, both group and self-reflections are included in the processing of information, and thus the construction of knowledge. Hands-on learning experiences are a natural fit in this learning theory with respect toward the surroundings, interactions and tools in a child’s world. From a Vygotskian perspective, the world is continually stimulating, therefore learners are constantly processing this information and constructing their own understanding (Rogoff, 1990; Vygotsky, 1978).

**The History of Conceptual Change Models**

The conceptual change model emerged from constructivist teaching philosophies (Georghiades, 2000) and research on scientific misconceptions (Wandersee, Mintzes, & Novak, 1994). The constructivist approach implies that students learn by making connections between their pre-existing knowledge and the new knowledge they construct from science instruction (Gilbert, Osborne, & Fensham, 1982). By using this pre-existing knowledge, students are set up to be active rather than passive learners, actively working new information into their current schemas.

Alternative conception research emerged from and was influenced by the conceptual change model and seeks to identify learners’ (teachers and students alike)
misconceptions or alternative conceptions of scientific concepts. Pfundt and Duit (1988) created one of the most comprehensive bibliographies on the subject, which lists around 1400 references related to misconception research in science education. Furthermore, the overarching findings were summarized by Wandersee et al. (1994) in the Handbook of Research on Science Teaching and Learning. The findings composed eight major claims:

1. Learners come to formal science instruction with a diverse set of alternative conceptions concerning natural objects and events.
2. The alternative conceptions that learners bring to formal science instruction cut across age, ability, gender, and cultural boundaries.
3. Alternative conceptions are tenacious and resistant to extinction by conventional teaching strategies.
4. Alternative conceptions often parallel explanations of natural phenomena offered by previous generations of scientist and philosophers.
5. Alternative conceptions have their origins in a diverse set of personal experiences including direct observation and perception, peer culture and language, as well as in teachers’ explanations and instructional materials.
6. Teachers often subscribe to the same alternative conceptions as their students.
7. Learners’ prior knowledge interacts with knowledge presented in formal instruction, resulting in a diverse set of unintended learning outcomes.
8. Instructional approaches that facilitate conceptual change can be effective classroom tools (p.195).

Alternative conception research shows that both students and teachers have alternative conceptions about science concepts, and it is difficult to make progress toward a scientific understanding. Since alternative conception research does not provide insight into promoting scientific understandings through instruction, science education research began to shift from identification of alternative conceptions toward instructional interventions to reconstruct knowledge and to promote scientific understanding.

**Early Models of Conceptual Change**

The influential beginnings of conceptual change research start with Piagetian learning and thought development theories occurring in stages and over time. Building
post-Piaget, influences include Thomas Kuhn’s concepts embedded in contexts containing internal structures and then fitting into external frameworks (Kuhn, 1962; 1970). Kuhn’s first model included his tenets of ‘global incommensurability’ and later was reworked to ‘local incommensurability’ indicating revision of only a partial concept meaning change occurs (Vosniadou, Vamvakoussi, & Skopeliti, 2008). Furthermore, in the seminal groundwork, Posner, Strike, Hewson and Gertzog (1982) link Piaget and Kuhnian works to define four foundational conditions for student conceptual change:

1. Dissatisfaction with one’s current conception
2. New conception is intelligible
3. New conception is plausible
4. Fruitful or potential to extend to other global circumstances.

Strike and Posner (1992) later expand on this theory to incorporate alternative conceptions that may not initially pre-exist but may be triggered instead through instruction; despite this, the core of their theory still stands. The field progresses with the work of Susan Carey. Carey’s conceptual change requires concept re-assignment to a “different ontological category” or the creation of new categories (Carey, 1991, Vosniadou & Skopeliti, 2005, Vosniadou et al., 2008). One of Carey’s foundations is the claim that even very young children develop theories and continually make predictions about natural phenomena from the world around them (Carey, 1999).

Vosniadou starts here and moves the field forward by conceptualizing conceptual change in terms of theoretical frameworks and mental models (Vosniadou & Brewer, 1992, Vosniadou 1994). Vosniadou’s work is concerned with how children learn and how their experiences with the natural world are incorporated into their larger
frameworks of understanding. Her work includes identifying children’s alternative conceptions not as a lack of coherence, or as a cognitive glitch, but as the result of children actively and creatively working toward a model of mental coherence. Vosniadou builds on Carey’s ideas of the foundational ideas of children, claiming it is a child’s own limited framework that constrains the building and production of scientific model for a concept. For example, the elementary school students in Vosniadou and Brewer’s (1992) research consistently constructed models of the Earth as being disc or rectangular flat shaped. Their models were based on their everyday experience and are what Vosniadou and Brewer label “initial” models because they have not yet been shaped by the scientific model of the Earth. However, older students constructed some synthetic models of the Earth, which incorporated scientific elements from instruction into their own non-scientific frameworks (Vosniadou, 1994; 1999). **Structure of concepts**

According to framework theorists’ view of conceptual change, students generate mental models and alternative conceptions that combine aspects of the scientific model with their initial models. Student models are confined by his or her own limited frameworks. The existing structures of the student’s personal framework theory need revision and eventually restructuring to allow for a fully scientific model to be supported. Students slowly revise their initial conceptual system over time by adding the elements of scientific explanation from instruction. During this process, students need instructional guidance to create larger theoretical constructions. Instruction needs foundational roots of the vast understandings that are brought to the classroom/instruction by students with
their own initial concepts, as formed by their worlds. As science educators we want to help students incorporate scientific components into their personal conceptualizations and frameworks. Students may eventually reach a full scientific understanding, or we may view them at a point in time where they have only incorporated scientific elements into their naïve models or created a hybrid or synthetic model.

**Conceptual Change as a process**

A student’s belief is not simply a card to be traded in and out of the system, independent of the other pieces. Vosniadou’s research has shown that children often have internal inconsistencies in their understandings and responses. This suggests that students incorporate new scientific fragments from instruction into their existing frameworks or initial conceptualizations. This system for assimilation of new information does not generally pose a threat when consistent with what is already known. When the prior conceptions are non-scientific, and the learner attempts to add scientific information to this structure, the learning outcomes are not productive and can lead to development of internal inconsistencies, alternative conceptions and ‘synthetic’ models of understanding. Vosniadou describes such ‘synthetic’ models as a result of the learner processing or attempting to synthesize the new scientific information with their pre-existing understandings gathered from world experience (Vosniadou et al., 2008). When a student already has the internal mental structures present that align with what the student perceives in the outside world, the student is merely assimilating this added information to an already present structure. When the student’s internal world/structure
must adapt to accept new information from the perceived outside world, the student must accommodate such information.

Of special importance are the long periods of time or gradual nature of the conceptual change process. The formation of more scientific and sophisticated models can only be facilitated after a “gradual lifting” of the student’s presuppositions informed by their framework theory (Vosniadou et al., 2008). Because learners construct their initial frameworks early in life based on interpretations of the world and they use additive and enhancement mechanisms to assimilate and accommodate this new and discordant information with their existing structures, the process is slow and gradual (Vosniadou & Brewer, 1992, 1994; Vosniadou, Baltas & Vamvakoussi, 2007).

Framework theorists are constructivist in nature guided by the ideals of domain specificity as they provide explanations of children’s active and creative construction and assimilation of knowledge. This is in contrast to others’ views supporting domain general conceptual change. The domain specific approach highlights the labeling and detailing of the changes occurring in both the content and the structure of knowledge. This approach also accounts for the mechanisms and strategies that are specific to these changes (Vosniadou et al., 2008). Vosniadou and colleagues cite the domain specific approach for providing insight and allowing for hypothesizing into the ways specific content topics are organized and re-organized by learners.

Cognitive Conflict/Cognitive Dissonance theories

Cognitive conflict strategies are derived from Piagetian constructivist views and cited as effective tools for teaching conceptual change (Duit, 1999). The strategies
involve making learners aware of their pre-existing conceptions on a particular science concept or phenomena. After the learner’s conceptions are made explicit, they are then challenged by presenting data or experiences in direct disagreement with their prior conceptions. Built in alignment with Posner et al.’s theory of conceptual change (1982) and the later Strike and Posner revision (1992), this strives to create a state of disagreement with the new evidence and prior conceptions. This conflict lays the groundwork for students becoming dissatisfied with their current conceptions and hopefully later accepting the new scientific notion as intelligible, plausible, and fruitful.

More recently, there has been emphasis placed on the impacts of cognitive conflict of students and how that may affect the learning process. Issues from cognitive conflict are discussed in the section titled “recent additions to the conceptual change theory.”

**Newer Perspectives of Conceptual Change**

**Knowledge as Pieces**

“If a concept is, in fact, a complex system, there is likely no point in the learning trajectory where we can unequivocally decide a person “has” the concept. It may always be a matter of degree and context” (diSessa, 2002, p. 54).

Leading the charge to challenge conventional conceptual change research is Andrea diSessa and his argument for ‘conceptual ecology’ (diSessa, 2002). diSessa critiques the majority of conceptual change research for its oversimplification from a naïve concept taking an unclear path and coming out the other side as an expert concept (diSessa, 2002). As he explains this model and his concerns, I am reminded of “black-
box” classroom studies, where we as researchers are often criticized for a lack of transparency in our research methodologies.

As outlined above, Vosniadou labels concepts as ‘models’ and diSessa takes issue with the framework theorist’s definition of concept. In lieu of labeling concepts as a thing/ontology/model or theory, diSessa labels concepts as a type of ideal ‘mental entity’ (2002). diSessa diverges from other researchers in that he rejects the idea of “concepts” and urges researchers to replace the notion of “concept” with a “variety of more carefully defined theoretical constructs,” called coordinated classes (diSessa & Sherin, 1998; diSessa, 2002). Continuing his critique, he asks what or who defines a concept? diSessa argues that in the traditional model, which I likened to black-box studies, a concept is a stand-alone construct, free from larger complex structures. It is these larger system constructs that diSessa believes are missing from the current research trend. The traditional model does not attempt to answer or explain in detail how this task of concept growth from naïve to scientific was actually accomplished. As evidence for his larger structural system, diSessa cites evidence of the diverse and complicated intermediate stages of learning students and teachers experience (diSessa, 2002). diSessa argues for a broader, more complex knowledge system where the naïve students’ conceptual elements undergo gradual change, augmentation with new elements and reorganization into new configurations from novice to eventually conceptually competent. As the field of ecology is a broad system of structures, diSessa argues for the same view regarding conceptual change.
P-Prims

DiSessa argues a child’s naïve knowledge consists of isolated pieces, or phenomenological principles or p-prims (diSessa, 1988; 1993). In diSessa’s view of conceptual change these p-prims are integrated into a larger, more comprehensive conceptual structure through reorganization and synthesis of p-prims. The overall collection of p-prims are what informs student explanations (Vosniadou, 1999). This is of stark contrast to Vosniadou’s coherency model, which states that students’ alternative conceptions are internally coherent and meaningful to the student, robust and resistant to change (Vosniadou, 1999). P-prims are diSessa’s response to Vosniadou and Brewer’s beliefs and presuppositions (Vosniadou & Brewer, 1992; Vosniadou, 1994). Of great importance and foundational to diSessa’s model is the nature of these p-prim ‘pieces’ being isolated in relation to each other.

Coordination classes

diSessa’s model for classes of scientific concepts, which are complex and multifaceted are what he calls coordination classes (diSessa 1988, 1993). diSessa argues not all information is transparent or visible in the world; instead, we actively work at finding ways to access this information and may often use different modalities to arrive at the same outcome. In lieu of declaring students as either having or not having a particular concept (e.g. labeling alternative or scientific), diSessa describes ways in which the student’s concept both works and does not work like that of an expert’s (diSessa & Sherin, 1998). This distinction in his 1998 work was a revision of earlier models and he further revises his terms again in 2006 to define coordination classes to encompass both
Perceptual and inferential tasks (diSessa, 2006). *Coordinated classes* are defined as classes of concepts important in science learning, and they are the underlying structure that allows for a student to see and read information around them (diSessa, 1998). Together the classes are systematically connected ways of obtaining information from the world. Well-developed coordination classes ensure students can infer the same types of information across different contexts (diSessa & Sherin, 1998; diSessa, 2006).

**Perceptual and inferential.**
The perceptual component is what diSessa labels a *readout strategy* (diSessa & Sherin, 1998, diSessa, 2006). The readout strategies “penetrate the diversity and richness of varied situations to accomplish a reliable ‘readout’ of a particular class of information” (diSessa, 1988). The student must choose which features from the current contextual state are related to the information and visualize that information as a system. Two types of coordination inform a learner’s readout: integration and invariance. The integration is how the learner processes new information to fit with existing knowledge structures. Invariance is when the learner notices non-congruence with some prior existing knowledge and has to adjust structures or use existing structures to make sense of this new knowledge element. The inferential component of coordinated classes is the *causal net.* This component uses a student’s reasoning strategies and body of knowledge to make inferences from the *readout* information (diSessa & Sherin, 1996, diSessa, 2006). The primary function of a coordination class is to allow students/learners to establish that information will apply across multiple circumstances and experiences. Overall, diSessa’s critiques of current trends calls for the field of conceptual change research to better define terms and refine thoughts on the one-size-fits-all
approach to concepts. diSessa calls for recognition of the multiplicity of types of knowledge and mental entities, shift toward smaller grain size/larger number of knowledge elements and the contextually within which conceptual change occurs (diSessa, 2002).

**Categorical Reclassification**

Chi and Roscoe (2002) argue that conceptual change is really just a repairing process where we must help students remove and/or correct their alternative conception to another lateral category. They label student alternative conceptions as ‘naïve’ knowledge and classify it by two properties; 1. It is often incorrect in comparison to what is scientifically acceptable and 2. It often (not always) hinders the learning of the new scientific concepts. This repairing process is a reassigning of categories or shifting across ontological categories. Chi and Roscoe define alternative conceptions as “miscategorizations of concepts across ontological categories” (pg. 25, 2002).

**Motivation**

The role of motivation as a key component in the conceptual change process has started to gain momentum over the last ten years (Sinatra, 2005). Dole and Sinatra’s (1998) Cognitive Reconstruction of Knowledge Model (CRKM) posits several types of motivation experienced by learners: the need for cognition, the perceived relevance of the content, dissatisfaction, or the social setting of the new content. Per the CRKM, the more motivated a student, the more likely they are to experience conceptual change. Likewise, the less motivated the student, the less likely they are to experience conceptual change and their existing conception is likely to remain. Mason and her colleagues further
explore conceptual change studies by examining the motivational constructs of students’ epistemological beliefs and topical interests (Mason & Boscolo, 2004; Mason, Gava, & Boldrin, 2008).

**Cognitive conflict**

There is a large and controversial body of literature on the effects of cognitive conflict (Clement, 2008; Guzzetti, Snyder, Glass, & Gamas, 1993; Limón, 2001). Many researchers oppose cognitive conflict in theory stating that it is not in congruence with the constructivist approach (Smith et al. 1993). Other researchers believe this discord with effective teaching can be productive (Clement, 2008; Hatano & Inagaki, 2003). It has been reported that introducing a controversial experiment or conversation and asking students to make predictions can be helpful in promoting fruitful discussions and can lead to deeper understanding of the scientific concept at hand (Hatano & Inagaki, 2003).

**Future Directions of Conceptual Change Theory**

**Metacognitive considerations for conceptual change**

Metacognition, or “thinking about thinking,” and reflecting on one’s own learning, has three major components: 1. knowledge about knowledge, cognizance of personal cognitive, social, and metacognitive expertise; 2. governing skills in which students plan and assess skills; 3. increasing proficiency and growth in reflecting on personal knowledge, skills and adapting these for use in new contexts (Flavell, 1979; White, Frederiksen, Frederiksen, Eslinger, Loper, & Collins, 2002). Georghiades separates his work from other metacognitive work with goals of "improving children’s ability to think" (Adey, Shayer and Yates, 1991). Instead Georghiades’ work had been aimed at
examining metacognition’s impact on more specific processes involved in conceptual change learning, explicitly durability and transfer of conceptions (Georghiades, 2000; 2004; 2006).

**Metacognitive Instances Approach**

Georghiades’ instructional approach incorporates brief (two to six minute) metacognitive activities such as classroom discussion, annotated drawing, concept mapping (Georghiades, 2001; Georghiades & Parla-Petrou, 2001) and journaling at selected points during the lesson and unit. Typically, teachers employ five or six of these strategies every lesson. The timing of the meta-activities was often planned but was also allowed to emerge at salient points of instruction. The teachers used these activities as they deemed fit according the class responses and discussions. A distinctive difference of his line of research is that metacognitive activities are fully integrated with typical teaching procedures (Georghiades 2006), in contrast with other researchers’ implementation of metacognition as a general, context-free thinking skill where specific time was carved out outside the typical lesson components (e.g., Adey et al., 1991).

There is one other key aspect of Georghiades’ metacognitive activities that is promising for future research, yet lacks serious empirical data to date, which seeks to raise the contextual awareness of students. This involves students and teachers defining contexts, noticing similarities and differences, and attempting to connect science concepts across contexts (e.g. transfer of science classroom concepts into daily life; e.g. physics knowledge applied to particle behavior in chemistry class).
Dynamic emergent structures

In an attempt to understand a new theory while taking into account the larger influencers; (diSessa/knowledge in pieces and Vosniadou/framework theorists), Brown (2014) takes a metaphorical emergent approach to see how these two might serve to create a more uniform theory. Although knowledge in pieces and framework theory are often in disagreement, they are in agreement that students’ conceptions are not unitary alternative conceptions. Brown likens the emergent structure to that of turtles in a pond; they are independent structures, but looking at the whole system, they are part of and dependent within the system. This view of dynamically emergent structures is similar to a biological view of structures; structures form dynamically and evolve, change, and grow dynamically (Towers and Davis, 2002). Utilizing the structure of this theory, knowledge in pieces, framework theory and the newer emergent theory, can be viewed as complimentary as each focuses on different aspects of the dynamic structure as a whole.

Overview of the Three Studies

Studies one and two are closely related as they deal with conceptual understanding and conceptual change around astronomy concepts. They both examine conceptual understanding and conceptual change that takes place with inquiry instruction but with two different populations: study one focuses on young children’s understanding and change while study two focuses on the in-service early childhood teachers’ understanding and change. Likewise, study three examines conceptual understanding of solution chemistry concepts with adults in an introductory-level college chemistry course.
Study One

This study describes young children’s understandings of the day/night skies, including identification of objects visible in the sky during different times of day. Young children are naturally curious about outer space and are fascinated by astronomical objects. This interest can lead them to raise questions about the astronomical objects and events they observe everyday (Kallery, 2011). Their interpretations of their everyday observations can cause them to develop their own ideas of the related phenomenon (Lelliott & Rollnick, 2010; Vosniadou & Brewer, 1994). From children to adults, lunar phenomena is one area that students have alternative conceptions. Although lunar concepts are one of the targeted areas in the National Science Education Standards and the newer Next Generation Science Standards (National Research Council, 1996, 2012; NGSS, 2013), studies indicate children across a wide range of ages and grade levels have difficulties understanding this topic (e.g., Barnett & Moran, 2002; Baxter, 1989; Broadstock, 1992; Stahly, Krockover, & Shepardson, 1999; Roald & Mikalsen, 2001; Schoon, 1988; Trundle, Atwood, & Christopher, 2007a).

Research regarding lunar concepts consists largely of studies that seek to describe children’s as well as pre-service teachers’ conceptual understanding, however, few studies have paid attention to the effectiveness of specifically designed teaching activities (Lelliott & Rollnick, 2010; Trundle, Atwood & Christopher, 2002). Results from studies focused on the effectiveness of the instructional interventions are very promising for elementary and middle school students (Barnett & Morran, 2002; Hobson, Trundle, & Sağkes, 2010; Stahly et al., 1999; Trundle et al., 2007a), and also for pre-service teachers.
(Bell & Trundle, 2008; Mulholland & Ginns, 2008; Ogan-Bekiroglu, 2007; Shen & Confrey, 2007; Trumper, 2006; Trundle et al., 2002, 2006, 2007b) in terms of promoting their conceptual understanding. Only a few studies, however, examined the effect of instruction on the change of preschool students’ understanding of astronomy concepts (Hannust & Kikas, 2007; Kallery, 2011; Valanides, Gritsi, Kampeza & Ravanis, 2000). The limited number of studies with preschool children focused mainly on children’s understanding of the shape of the Earth and sun, gravity and day-night cycle. The extant literature suggests there are no studies on lunar concepts that examine the effectiveness of a play-based instructional sequence on preschool children’s conceptual understanding.

Recent research indicates the importance of early childhood science education especially for children in high-need schools. Early childhood specialists and science educators agree that science is a natural fit with the way young children explore and try to explain their environments. The preschool classroom can capitalize on young children’s explorations and be highly engaging and consistently interesting to young children (French, 2004). In addition, play is considered as an integral part of early childhood curricula, yet there is a lack of evidence about the effectiveness of play as a pedagogical tool for young learners in general and for children’s learning of science concepts in particular. Moreover, instructional strategies and models that describe the effective use of the play as a pedagogical tool are limited. This study aims to examine the effectiveness of a play-based inquiry instruction on preschoolers’ conceptual understanding of the targeted astronomy concepts. More specifically, the following
research questions guided study one: What do young children understand about the day and night sky? What do they understand after play-based, inquiry instruction?

**Study Two**

In this study, the first research goal is to examine preschool teachers’ conceptual understandings about the day and night skies, and patterns in and cause of lunar phases both before and after an inquiry-based professional development (PD), which integrated technology. The study’s second research goal investigated the efficacy of the teachers’ instructional interventions with preschool children. The four teacher-participants in this study were the teachers of the young children who were the participants in study one. Case studies are presented from the four teacher participants, including an analysis of the group as a whole, followed by a discussion of the findings from the classroom observations.

In order to present young children with these types of inquiry instruction, it is necessary for the teachers of these young children to be familiar with the necessary conceptual understanding of lunar concepts. Internationally there is a trend where the majority of early childhood teachers have very little science content training (Appleton, 2003; Fleer & Robbins, 2003). Early childhood teachers’ science content knowledge is low, and teachers often are unaware of their lack of content knowledge. Teachers also are unaware of how this lack of content knowledge influences their ability to provide science experiences for young children (Garbett, 2003). Early childhood teachers lack confidence in their science content knowledge and science education pedagogy (Fensham, 1991; Garbett, 2003). Despite teachers’ lack of science training and low self-
efficacy in their science abilities, young children’s experiences with and interest in science is strong (Cummings, 2003; Fleer & Robbins, 2003). Preschool teachers, however, have indicated that well-designed professional development experiences enhanced their abilities to learn concepts, including concepts in mathematics and science, and the experiences improved their teaching practices (Katz, 1999). Well-designed and effectively implemented professional development experiences can lead to improved preschool program quality (National Research Council [NRC], 2001).

Although previous research has included elementary and early childhood teachers’ understandings of astronomy concepts, no previous research has exclusively focused on preschool teachers. The current study addressed this research need by describing preschool in-service teachers’ conceptual change through inquiry-based instruction during a professional development. Not only were we interested in the teachers’ understandings but also how their knowledge transferred into their classroom practices. Case study findings are presented from the four teacher-participants, as well as an analysis of the group as a whole.

**Study Three**

Study three also centers around conceptual understanding and conceptual change theory of learning as this study aims to identify students’ conceptual understandings of under-researched areas of solution chemistry.

The purpose of this study aims to perform the first English implementation of The Nature of Solutions and Solubility—Diagnostic Instrument (NSS–DI), the two-tier, multiple-choice instrument that includes the various associated aspects of solution
chemistry. The current instrument was developed and validated in Turkish for identifying Turkish high school students’ conceptions of solution chemistry. This instrument differs from other multiple-choice instruments (Pinarbasi, Canpolat, BayrakÇeken, & Geban, 2006; Uzuntiryaki & Geban, 2005) as it employed the two-tier format, multiple contexts, and multiple modes and levels of representation. This instrument is essential because, even with extensive research on students’ conceptions regarding the nature of dissolving (Calik, Ayas & Ebenezer, 2005), there is limited research on students’ conceptions of some of the other conceptual aspects of solution chemistry (e.g., factors affecting solubility of solids and gases, the types of solutions relative to the solubility of a solute, concentration of solutions, and the electrical conductivity of solutions) (Adadan & Savasci, 2012; Calik, Ayas, & Coll, 2010; Devetak, Vogrinc, & Glaar, 2009; Teichert, Tien, Anthony, & Rickey, 2008). Therefore, with implementation and statistical evaluation of this instrument, future studies may be carried out to extend this body of research about students’ conceptions of solution chemistry.

Conclusion

Teachers must be aware of the original conceptions students hold, as these will influence the ways in which they interact with new content (Hewson, 1982). It is not enough for teachers to acknowledge that students come to instruction with differing naïve conceptions; teachers also need to take responsibility for engaging students and designing instruction that is likely to facilitate student conceptual change (Hewson, 1981).

From a science education researcher perspective, the more we know about alternative conceptions and the mechanisms of conceptual change, the better we can
prepare our pre-service teachers and in-turn improve science education in the preschool to college settings. There are many competing and emerging theories of conceptual change, all of which make this area of study so intriguing. Understanding initial conceptions and how students form them from their everyday interactions, as well as understanding their meaning-making processes, helps us as teachers and researchers gain insights into the minds of learners.
References


Chapter 2

Play-based Science Instruction to Teach Preschool Children Space Science Concepts

Abstract

This study describes young children’s understandings of the day and night skies, including identification of objects visible in the sky during different times of day. Forty-four preschool children participated in the study, and twenty-one children received a play-based instructional intervention. Data were collected through semi-structured interviews both before and after the play-based instructional sequence, and were analyzed using the constant comparative method. Results indicated that older children started with a greater understanding of the day/night sky than younger children, and made greater gains in the targeted content areas. Prior to instruction, few children could provide evidence for the time of day or identify objects visible in the day or night sky. Post-instruction, 79% of four and five year olds could provide evidence for time of day, compared to 29% of the two and three year olds. The number of two and three year olds who could identify objects visible in the day sky remained the same pre to post (14%), but a large increase was seen (of 71%) who were able to identify objects in the night sky post-instruction. Post-instruction, sixty-four percent of the four and five year olds could identify objects in the day sky and 86% could identify objects in the night sky. Findings suggest that children are able to
make observations of the sky and their understanding and evidence of space science concepts increased after a play-based inquiry instructional sequence.

**Introduction**

Young children are fascinated by the day and night skies. This interest leads them to raise questions about astronomical objects and events they regularly observe in their everyday lives (Kallery, 2011). Children interpret these everyday observations through their existing mental models, which leads them to develop their own ideas of the related phenomena (Lelliott & Rollnick, 2010). A large body of research on young children’s ideas of astronomy indicates that children’s notions can be different from the accepted scientific views (Küçüközer & Bostan, 2010; Lelliott & Rollnick, 2010; Stahly, Krockover & Shepardson, 1999). These alternative conceptions can be persistent and difficult to change through instruction and, in turn, can pose obstacles to students’ further conceptual development (Hewson & Hewson, 1983).

Intersecting play as a developmentally appropriate practice with conceptual change theory provides a rich framework for research and a setting for children’s growth. Each of these two fields can inform the other and may help researchers examine the possibilities of play pedagogies for promoting conceptual change with young children. Play provides young children opportunities for discussion that bolsters students’ feelings of success and safety, an imperative for promoting conceptual change (Bruning, Schraw, & Ronning, 1999; Scott, Asoko, & Driver, 1991). While research has been conducted regarding play activities with a lens for science learning, these studies have primarily focused on either the actions, inquiries, or ways in which science naturally emerges in
these settings (e.g. Inan, Trundle & Kantor, 2010). In the current study, these two frameworks, play and conceptual change, are merged to view the child from a ‘wholeness’ approach (Vygotsky, 1998; Hedegaard & Fleer, 2008). Vygotsky (1998) argued for this approach as a way to better understand research and education of young children.

**Conceptual Framework**

“Play is not a break from learning, but a pathway toward learning”

(Wood, 2014)

The role of play in children’s development and learning has long been recognized by both early childhood researchers and practitioners (Bodrova & Leong, 2003). Play is considered as an effective pedagogical tool for young learners (Siraj-Blatchford, 1999) and learning through play has been emphasized in early childhood curricula in many countries including Australia (Australian Government Department of Education, 2009), England (Department for Education, 2012), and Turkey (Milli Eğitim Bakanlığı, 2012). Play is included in US state standards for preschool, and the National Association for the Education of Young Children ([NAEYC], 2009) highlights the importance of play for children’s learning. Play, along with encouraging children’s playfulness, is experiencing a resurgence and coming to the forefront of research with young children (e.g. Gray, 2013; Brown & Vaughn, 2009; Russ and Wallace, 2013; Wood, 2014; Elkind, 2007). Play practices in classrooms are cited as not only building positive attitudes toward learning, but also towards developing language, gross and fine motor skills, content (e.g.
science, social studies) literacies, mathematical concepts, social-emotional development, artistic literacies, reading, and language arts (Wood, 2014).

In looking to natural sciences education, we often focus on two primary questions: what to teach and how to teach (Tsitouridou, 1999). “What to teach” encompasses the content and process of science. When examining “how to teach,” several pedagogies are supported as developmentally appropriate and effective at engaging preschoolers with science in school settings (NAEYC, 2009). The National Research Council (NRC, 2000) states that the best science practices for preschool learning are to choose “the right tool for the right task at the right time” (p. 11). The National Association for the Education of Young Children (NAEYC) seeks to promote excellence in early childhood education by providing frameworks for best practices, called developmentally appropriate practices. Developmentally appropriate practices (DAP) are grounded in inquiry and embrace constructivist and social-constructivist approaches to teaching and learning (NAEYC, 2009). Play is the work of children, and it is through this play that children are growing socially, emotionally and academically. Without adult guidance, very young children are naturally forming ideas and conducting their own investigations about scientific phenomena. As a baby sits in a high chair throwing a spoon on the ground he/she is drawing early conclusions about gravity, object permanence, and cause/effect relationships. Play supports creativity, problem solving skills, communication and language skills, as well as being enjoyable and purposeful.

Play honors children’s prior knowledge, as they are the directors of the action. Blake (2004) describes how it is paramount for children to know how and why
information is relevant in order to connect prior knowledge with scientifically appropriate observations. Play provides children with engaging experiences where their prior knowledge is utilized and valued. Adults can make these environments more conducive to child-centered investigations; e.g. teachers may set up a water table with items of differing densities, or provide magnifying glasses and different rocks and/or minerals. Children can be guided in their observations and investigations by both the environment being conducive to child-directed experiences and by more knowledgeable others (e.g. teachers, aides, learning guides) pointing out what is important to observe (Vygotsky, 1976; 1978).

Like research on play, conceptual change research has been a large part of the growing research base over the last thirty years. The influential beginnings of conceptual change, very much in line with the history of developmentally appropriate practices in early childhood education, start with Piagetian learning and thought development theories occurring in stages and over time. Post Piaget, influences on conceptual change include Thomas Kuhn’s concepts embedded in contexts containing internal structures and then fitting into external frameworks (Kuhn, 1962; 1970).

From a constructivist perspective I view classrooms as spaces where children and teachers engage in dialogue and construct knowledge through everyday classroom settings and interactions. While there are many models of conceptual change, this study frames conceptual understandings and change through the lens of theoretical frameworks, mental models, and as the active accommodation of new concepts into a person/child’s existing schema (Vosniadou & Brewer, 1992, Vosniadou, 1994). Vosniadou’s work,
which is concerned with how children learn and how their experiences with the natural world are incorporated into their larger frameworks of understanding, guided the design and implementation of this study. This framework includes identifying children’s alternative conceptions not as a lack of coherence, but rather as the result of children actively and creatively working toward a model of mental coherence.

**Structure of concepts and Conceptual Change as a process**

According to Vosniadou’s model of conceptual change, students generate mental models and alternative conceptions that combine aspects of their initial models with the scientific model. As previously noted, a student’s mental model is confined by his or her own limited framework. The existing structures of the student’s personal framework theory need revision and eventually restructuring to allow for a fully scientific model to be supported. Students revise their initial conceptual system slowly over time by adding elements of scientific explanation from instruction. Play promotes dialogue and creativity with new ideas, materials, and concepts, and encourages children to act out processes during which they are making meaning and constructing new ideas. Throughout this process, teachers can provide instructional guidance to help students create larger theoretical frames. Instruction requires foundational roots of the vast understandings that are brought to the classroom/instruction by students with their own initial concepts, as formed by their worlds. As science educators, our goal is to help students incorporate scientific components into their personal conceptualizations and frameworks.
In this study two frameworks are merged, play and conceptual change, to view the child from a ‘wholeness’ approach (Vygotsky, 1998; Hedegaard & Fleer, 2008). Vygotsky (1998) argued for this approach as a way to better understand research and the education of young children. Each of these fields honors the learner and can inform the other. This layering may also provide new possibilities for research designs for conceptual change theorists.

**Purpose of the Study**

Although play is considered as an integral part of early childhood curricula, there is a lack of evidence about the effectiveness of play as a pedagogical tool for young children’s learning of science concepts. Therefore, this study aims to examine the effectiveness of a play-based inquiry instruction on preschoolers’ conceptual understanding of developmentally appropriate astronomy concepts.

There are a limited number of science-related studies with young children in the literature base, and the available studies focused mainly on children’s understandings of the shape of the Earth and sun, gravity, and the day-night cycle (e.g. Vosniadou & Brewer, 1992, 1994; Küçüközer & Bostan, 2010). Few studies targeted children’s understandings of other celestial objects and their apparent movement across the sky (e.g., Küçüközer & Bostan, 2010; Piaget, 1972; Plummer, 2009; Za’rour, 1976). Our review of the literature found no previous studies that solely focused on astronomy concepts targeted in state standards for preschool. These concepts include using personal observations to describe day, night, the sun, stars, and moon, and to provide evidence for their knowledge. The current study was designed to address this gap in the research. The
study includes the concepts of identifying the time of day (day or night), providing evidence for the time of day, recognizing the colors of the day and night skies, identifying celestial objects that can be observed in the day and night skies, and recognizing the times of day when celestial objects can be observed.

More specifically, the following research questions guided the study: What do young children understand about the day and night sky? What do they understand before and after a play-based, inquiry instruction?

**Methods**

**Context and Participants**

The research was conducted in two Midwestern U.S. preschools. Forty-four children participated in the study. The children ranged in age from two to five years. The control group composed of twenty-three children and included sixteen African American, four Hispanic, two European American, and one Ethiopian child. The treatment group, which received the instruction, included twenty-one children, including sixteen African American, four European American, and one parent-identified mixed-race child. Both classes included children who lived in high levels of poverty. Eighty percent of the 2-3 year-olds and 95 percent of the 3-5 year-old children received publicly funded childcare. The control group children were enrolled in two different self-contained classrooms, one involving two and three-year-olds (n = 7) and the other included four and five-year-old children (n = 14).
Instructional Intervention

The instructional intervention, which included play using the Learning Cycle for preschool science and integrated guided science instruction, took place over six school days (Figure 1; Trundle & Smith, in press). The specific daily objectives and activities are further outlined below as well as in Appendix A. The science learning cycle builds on the 5-E instructional model (Bybee & NCIS, 1989). The pre-k cycle begins with play, allows students to explore concepts and materials in a variety of ways, and provides opportunities for students to discuss and debrief their discoveries and the major takeaways from each lesson. Each cycle of instruction (play, explore, explain) focuses on a different topic: day sky, night sky, and comparisons of the day and night skies. While each cycle included instructional objectives, the lessons were child-centered and incorporated the children’s interests, and were emergent from their free choice play.

![Preschool Learning Cycle](image)

Figure 1. The Preschool Learning Cycle for Science (Trundle & Smith, in press)
Instructional Sequence

Day instruction
To begin the unit and encourage play, diurnal stuffed animals were introduced by asking questions such as, “What time of day can this animal be observed”? A ‘campsite’ with a tent was located in the dramatic play area. Children’s ideas and own uses for the materials emerged from their play. During their play, the researchers observed children describing activities they might do during the day while camping. A CD of daytime nature sounds played in the camping area while the students staged a pretend campfire, used utensils to ‘cook’, acted out collecting berries, fishing, washing dishes in the stream, and singing camp songs. The play materials were available for the children to use for play one school day before the guided instruction began and were left in the classroom for additional play on the day of the guided daytime instruction.

To introduce the concept of daytime and objects that can be observed in the day sky, the teacher read aloud from the day sections of the nonfiction texts Day and Night (Halko, 2011a) and Day and Night on the Farm (Halko, 2011c). The teacher drew children’s attention to photographs, which depicted the color/brightness of the daytime sky and the objects visible in the sky (sun, moon). The children also went outside and made observations of the daytime sky in nature and recorded their observations using clipboards, blue paper (selected over black paper), and white and yellow colored pencils. Students then compared their observational data taken in nature to images from the planetarium software, Starry Night from Imaginova, which was projected on the classroom wall. The children compared their observed data to both the text and software
images. The guided instruction on the day sky and objects seen in the day sky took place during one school day and the entirety of the activities lasted about one hour.

The focus of this instructional sequence was the color of the day sky (blue), and celestial objects observable in the day sky (sun and moon). The targeted concepts for the instruction included observing, describing, and providing evidence for the day sky.

**Night instruction**

To transition from day to night sky concepts, the teacher introduced stuffed nocturnal animals and a CD of night sounds to the classroom. Self-directed play again emerged from student’s free use with the materials. From the observed engagements, the teacher responded with class discussions, which included activities they could do at night while camping. The students pretended to make s’mores, look at stars, sing around the campfire, and sleep in the tent. Children played and explored with the nighttime camping materials for one school day prior to the intentional learning engagement and instruction of the night sky. As before with the daytime play materials, the nighttime play materials were left in the classroom centers for further exploration on the day of the more intentional learning sequence.

To move into the exploration phase of the learning cycle and introduce the concepts of nighttime and objects in the night sky, the teacher read from the night sections of the nonfiction texts *Day and Night* and *Day and Night on the Farm* (Halko, 2011a; Halko, 2011c). She focused the children’s attention to photographs, which depicted the color of the nighttime sky and the objects visible in the night sky (stars, moon). The children looked at a projected image of the night sky from the *Starry Night* software. The children were asked what they could observe about the night sky. The
teacher focused students’ attention on the fact that although the moon was not currently visible in the projected image, sometimes we can see the moon in the night sky. The teacher asked the students if they could count the stars, and the students indicated the stars are too numerous to be counted. Next, the teacher drew their attention to the arrangement of the stars. Students observed and discussed how stars are clustered and not evenly spread across the sky. The students recorded their observations by drawing on black paper (selected over light blue) with white and yellow colored pencils, trying to recreate the patterns and clusters of stars. The focus of this activity was the night sky looks black, which celestial objects are observable in the night sky (moon and stars), and the stars appear in a pattern in the sky. The targeted concepts for the instruction included observing, describing and providing evidence for the night sky. The guided instruction of the night sky and objects that can be seen in the night sky took place during one school day and the entirety of the activities lasted approximately one hour.

**Day and night comparison**
The final series of instruction focused on the comparison of the day and night skies. Prior to the intentional instruction, play emerged as all the diurnal and nocturnal animals were placed in the classroom stations and CD’s of day and night sounds were played alternatingly. Conversations were overheard where children were acting out daytime play with the diurnal animals, as well as nighttime scenarios with the nocturnal animals. Other imaginative play conversations were observed with children discussing which animals would “play” together or “be friends” based on the time of day or night that they would be awake. For example, in one child-created scenario, the possum was not friends with the robin, as they would have no interactions or “play-dates” during each
of their typical days. The campsite was still in use in the dramatic play area, and the play materials for both day and night were available (e.g. flashlights for night and backpacks for day hikes). Children acted out different activities around dramatic and/or imaginative play utilizing spaces of the entire room (e.g. fishing, acting out stories with animals, ‘sleeping’ in sleeping bags, singing camp songs and/or storytelling). The play phase with both the day and night materials lasted one school day.

The following day, moving into the more intentional portion of the learning cycle, the teacher read, in entirety, the nonfiction text Day and Night in the Woods (Halko, 2011b). The teacher drew children’s attention to photographs, which depicted the colors/brightness of the daytime and nighttime skies and the objects visible in the day (sun, moon) and night (stars, moon) skies. The class discussed their earlier observations of the day and night skies and reflected on their learning up to this point. The children found similarities and differences in their observations of skies in nature, text, and technology simulations. The class completed a class data chart on a large poster board, with two vertical columns labeled “day” and “night”. Along the left side, two rows were labeled “color” and “objects in the sky”, and pictures and squares of colored paper (black and light blue) were provided. The students described the day sky as light blue/bright, and the night sky as black. Next, the students indicated that the sun and moon can be visible during the day, and that stars and the moon can be seen at night. Selected children placed the photographs in the appropriate sections of the chart. After the large group instruction, the students created their own data charts in a similar fashion by selecting and gluing colored paper and photographs of celestial objects onto their personal chart, which
mimicked the class chart. The intentional learning of comparing the day and night skies took place during one school day. Similar to the other guided lessons, the discussion and activities lasted approximately one hour.

Data Gathering

Qualitative data were gathered through semi-structured interviews with the children (Appendix B), children’s artifacts, videotaped classroom observations, and field notes. All interviews and observations were recorded and transcribed. Field notes also were recorded during the interviews, and notes were used during the transcription of the interview data. The interview questions were used to assess the preschool children’s understanding of astronomy concepts and were constructed from the state preschool and the Next Generation Science Standards (ODE, 2013; NGSS, 2013). The transcribed data were coded and qualitatively analyzed to identify patterns of understandings, including alternative conceptions, among the children.

Data Analysis

Qualitative Data Analysis

The constant comparative method was used to analyze the data. The constant comparative method continuously questions, compares, and delimits the data (Glaser, 1965; Glaser & Strauss, 1967). Similar analytic methods have been used in other science education conceptual change studies and across discipline areas including the particulate nature of matter (Adadan, Trundle, & Irving, 2010), tides (Uçar & Trundle, 2011), seasons (Wild & Trundle, 2010), and moon phases (Trundle, Atwood, & Christopher, 2007a; 2007b).
Three coding strategies are described in the constant comparative method; open, axial, and selective coding (Charmaz, 2000; Strauss and Corbin (1990). For this study selective coding was used for the data, as participant answers were sorted into a larger schema of scientific or non-scientific/alternative understandings. Selective coding is described as "The process of selecting the core category, systematically relating it to other categories, validating those relationships, and filling in categories that need further refinement and development" (p. 116, Strauss and Corbin).

The first phase in the qualitative data analysis was to transcribe the video taped interviews. Transcriptions were made by key personnel researchers in order to prevent the loss of information and to gain a larger perception of the data set as a whole. After the transcriptions were completed, transcripts were reviewed multiple times before coding was done by the research team. Categorization of alternative and scientific conceptions was based on the same categorization developed by Trundle et al. (2007a)

From the qualitative data gathered, the research team, including the primary investigator and key personnel, first cross-referenced key words or remarks and then generated quantitative categories (scientific/non-scientific) from which to develop further theoretical properties (Glaser, 1965). Vosniadou describes alternate conceptions as models that differ from the scientific consensus viewpoint (1991). Constant comparative analysis allows for the student’s conceptions to be coded as “scientific” or “non-scientific/alternate” as appropriate. These categories were based on previous research with elementary students’ conceptual understandings of astronomy concepts (Hobson, Trundle, & Saçkes, 2010; Trundle, Atwood & Christopher, 2007a).
Findings

This section is organized to present the results of the qualitative and quantitative analysis of both the pre-test and post-test assessment of the young children’s understanding of lunar concepts. Statistical procedures incorporated in the Statistical Program for the Social Sciences (SPSS Version 22 for Mac) were used to analyze responses to the pre- and post- instruction conceptual understanding interviews and existing alternative and scientific conceptions. For the data obtained from the pre-test, a Mann-Whitney test was used to assure internal consistency of understanding between the treatment and control groups. Post instruction the following statistical procedures were applied: a) internal consistency reliability analysis b) population mean ranks differences from pre to post on the treatment groups c) one-way analysis of variance by ranks of both treatment and control groups post instruction.

Table 1
Classrooms and participant numbers by school

<table>
<thead>
<tr>
<th>School Site A</th>
<th>2- and 3- year old classroom</th>
<th>4- and 5- year old classroom</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7 (treatment group)</td>
<td>14</td>
</tr>
<tr>
<td>School Site B</td>
<td>10</td>
<td>13 (treatment group)</td>
</tr>
</tbody>
</table>
Quantitative Data Analysis

Prior to the analysis of the instructional intervention, a Mann Whitney U-test was run using the pre-interview data to determine whether the treatment and control groups were statistically equivalent in their current understandings of the day and night skies. Prior to any interventions, no statistically significant differences were found in student understandings across the 2- and 3-year old treatment and control groups ($z = -1.18; p = .24$) or the 4- and 5-year old treatment and control groups ($z = -1.58; p = .11$) Since both $p$ values are $>0.05$, the differences in understanding across the treatment and control groups did not reach significance. A Mann Whitney U-test was employed given the smaller sample size, the statistical measure is more appropriate than it’s parametric equivalent, the t-test.

Treatment Groups

Results are broken out by age groups/classrooms: 2- and 3-year olds and 4- and 5-year olds. In the following section, treatment groups are discussed first followed by a between-groups discussion.

2- and 3-Year Olds

Pre-instruction
Prior to instruction, only three of the seven two and three-year-old children (43%) were able to identify the outside sky as a day sky. Only one of these children (14%) was able to provide evidence to explain how they knew it was day. The majority of the children did not have understanding of celestial objects that could be seen in the day or night sky. However, children did have a fairly good scientific understanding of the colors of the day (71%) and night skies (57%). This age group scored highest (86%) on
knowing the stars were observable in the night sky, 57% of the 2/3 year old group knew
the moon could be observed in both the day and night skies and (42%) associated the sun
with the day sky.

**Post-instruction**

After instruction, six of the seven (86%) 2- and 3-year olds were able to identify
the time of day, and two of these children (29%) were able to provide evidence for how
they knew it was daytime. Gains were seen with more children (5 of 7) were able to
identify what objects are visible in the night sky after instruction as compared to two
children prior to instruction. However, the same number of children (1; 14%) were able
to identify the objects visible in the day sky after the instructional intervention. Student
understandings of the colors of the day and night skies increased, 100% and 71%
respectively. Additional increases were seen in that two students gained further
understanding of the moon being observable in both the day and night skies. Results from
the 2- and 3- year old treatment group pre and post instruction are presented in Figure 2.

Results for the observation time of both the sun and stars were unanticipated, as
understandings of these two concepts decreased with instruction. In hopes of
understanding this finding, weather patterns were examined on the days of data collection
as well as the days leading up to the interview events. The pre-interviews for the 2- and
3-year old control groups were conducted over two days, the first day was raining and the
second day was overcast and had thunderstorms earlier in the morning prior to the
interview. In looking at the post interview weather conditions, again the interviews were
conducted over two days. The first day, three of the seven control group children were
interviewed and the weather was overcast. The second day of interviews had clear skies,
and four of the seven control group students were interviewed on this day. Given that the post-interview days were either sunny or clear skies, I cannot infer the weather was a factor in the decreased number of students knowing when the sun was observable.

Figure 2. 2- and 3- year olds Treatment Group Conceptions Pre- and Post-instruction

In comparing the treatment and control groups from the 2- and 3- year old classrooms (Figure 3), the data show positive student growth in conceptual understanding of the related day and night concepts. Since the treatment and control groups differed in the number of children, these scores were compared using percentage of scientific understandings on the post-interview. The treatment group outperformed the control group in almost all areas.
Figure 3. Treatment/Control groups Two and Three-Year Olds post-instruction

4- and 5-Year Olds

Pre-instruction
The treatment group of 4- and 5-year olds consisted of 14 students in one self-contained classroom. In contrast to the younger children, thirteen (93%) (n=fourteen) of the four and five year olds were able to identify the time of day of the interview before instruction. However, only five of the fourteen children (36%) were able to provide evidence for how they knew it was daytime. Eleven children (79%) associated the sun with the day sky and twelve children (86%) associated the stars with the night sky. The least known time when a celestial object could possibly be observed was that of the moon with eight children (57%) providing a scientific response pre-instruction. Eleven children (79%) had scientific understanding of the color of the day sky while ten children (71%)
held scientific understandings of the color of the night sky. The section of least student understanding was observed when children were asked, “what objects they could see in a day sky” and “what objects can be observed in a night sky”.

**Post-instruction**

Post-instruction, the same number of children (13) as pre-instruction could identify the outside sky as “day sky”. Eleven of the fourteen (79%) 4- and 5-year olds could provide evidence for how they knew it was day, an increase from five children providing evidence before instruction. Nine of the children (64%) were able to identify objects in the daytime sky and twelve (86%) were able to identify the objects visible in the nighttime sky. Gains were seen in knowing when the moon could be observed as well as objects in the day and night skies. The largest gains were seen in children being able to provide evidence for how they knew it was daytime. Overall results from the 4- and 5- year old treatment group are presented in Figure 4.
In looking across the treatment and control groups (Figure 5), gains are visible with the treatment group children. While there were many areas of improvement, the
treatment group students demonstrated a much higher understanding of the observation times of the moon and being able to provide proper evidence for how they knew it was day at the time of the interview. These results for providing evidence will be expanded upon further in the discussion section below.

**Cross Age Group Comparison**

Similar to the 2- and 3-year old group, there were unexpected results with the 4- and 5-year olds. A slight decrease was observed in the number of children who were able to identify the color of the day sky. In looking at the weather patterns on the interview days, no inferences could be made about the weather affecting this decline. The day was cloudy and overcast on the day of pre-instruction interviews. In looking at the weather of the week before the pre-interviews, most of the days were also listed as overcast by local and national weather recorders; some of the days included light snow and the temperatures varied from 29-59 degrees Fahrenheit. On the other hand, the skies the week of post-instruction interviews were mostly clear with scattered clouds and temperatures ranging from 50-80 degrees Fahrenheit. Likewise, there was also a slight decline in scientific understanding of knowing when the stars could be observed. Again, the weather patterns for the interview weeks do not point to any clear linkages with student understandings.

**Statistical Analysis**

**Treatment Groups**

Results from statistical analysis of the item(s) difficulty index demonstrated that the most difficult question for the children in the treatment group pre-instruction was the
question requiring children to provide evidence for how they knew it was daytime. Only six of the 21 children provided a scientific response to this question, and only one of those children was in the younger (ages 2-3) group. The easiest question was the question that required children to state what time the stars can be observed. The majority of the children in the treatment group (19 of 21 children) provided scientific responses to this question. Post-instruction, the *how can you tell it is a day/night sky* (being able to provide evidence) question becomes easier for many children. Reliability coefficient of the observed scores for the pre-interview was KR-20=0.60 and post interview was KR-20=0.72.

**Treatment and Control Groups**

A Wilcoxon Signed rank test revealed a statistically significant time effect from pre- to post-intervention (z= 2.70, p = 0.007) with a moderately large effect size (r = .41), suggesting children’s conceptual understanding increased from pre- to post-assessments. The median score increased from pretest (Md = 17.7) to posttest (Md = 19.0). A Kruskal-Wallis test revealed a statistically significant difference in the post scores across the age levels and treatment groups (Gp1, n = 7; 2-3 treatment, Gp2, n = 10; 2-3 control, Gp3, n = 13; 4-5 control, Gp4, n = 14; 4-5 treatment), x2 (3, n = 44) = 9.3, p = .026. The older treatment group recorded the highest median score (Md = 7.50); the 4-5 control group and the 2/3 treatment group both recorded the same median scores (Md = 6.00), the 2/3 control group recorded the lowest median score (Md = 4.50).

An internal consistency reliability analysis was run for all groups; treatment and control and the KR-20 coefficient was 0.69 for the pre-interview assessment. Likewise,
the KR-20 coefficient was 0.64 for the post-interview assessment. These values suggest that considering the number of interview items, the nature of assessment and respondents observed scores have an acceptable level of reliability.

**Age Differences**

Older children obtained significantly higher scores than younger children (F (1, 42)=8.92, p=0.005, η=0.17). Results of Differential Item Functioning analysis (DIF) demonstrated that older children were more likely to provide a scientific response to the following interview questions: objects you can see in day sky ($\chi^2=5.83$, df=1, p=.016) and when can you see the moon ($\chi^2=4.99$, df=1, p=.026).

**Discussion and Conclusion**

The older children started with a greater understanding of the day and night sky than the younger children, and also made greater gains in most areas. Prior to instruction, many children could not provide evidence for the time of day or identify objects visible in the day or night skies. After the instructional intervention, the majority of the 4- and 5- year olds had gained almost full understanding in these areas. Sixty-four percent could identify objects visible in the day sky, 86% could identify objects visible in the night sky, and 79% could provide evidence for the time of day. In addition, almost all (86%) of the two and three year olds could identify day, and many children had made gains in other standards-based targeted areas. In looking across the age groups, both treatment groups saw a decline in scientific understanding for the observation time of the stars. Young children are often in bed or asleep when the stars are visible; since this limits their observational time, we must question how this plays into young children’s
understandings and schemas of the night sky. Early bedtimes, weather, and light pollution are all limitations to young children’s observational time and knowledge. The current study’s small sample size is also noted as a limitation to this study. Future studies should be conducted with a larger sample size that proportionally represents boys and girls as well as children from families from a broad range of socio-economic statuses. Another limitation of the current study is the disproportionate time-on-task between the treatment and control groups.

Play is so highly regarded in young children’s lives and educational opportunities that it has been recognized by the United Nations High Commission for Human Rights as a right of every child” (Ginsburg, the Committee on Communications & the Committee on Psychosocial Aspects of Child and Family Health, 2007, p. 182). In the current study the majority of observed play is classified as ‘pretend play’, or where “a pretender knowingly and intentionally projects some mentally represented alternative onto the present situation in the spirit of play” (Lillard, 1993). Lillard, Learner, Hopkins, Dore, Smith and Palmquist (2013) provide a comprehensive review of the literature on pretend play and its supports to the healthy development of children. The take-away message of their review states that more evidence is needed to support the importance of play for development (e.g. social, emotional and cognitive). It seems we have created a paradox where play is highly regarded yet we have no large research base to reference. Hence, there is a call for research. While the current study was low in participant numbers, it provides a groundwork for examining conceptual change through a developmentally appropriate framework for young children—play.
Without instruction, the majority of the youngest preschoolers (2 and 3 year olds) did not have scientific understandings of the standards-based astronomy concepts. The findings of this study suggest that young children can make observations about, describe, and provide evidence for the day and night skies. The findings also demonstrate the varied potential of day and night activities in a child-centered, play-oriented classroom. Only twelve states have standards for preschoolers, and four have standards directly applicable to this research project regarding the day and night cycle (Saçkes, Trundle, & Flevares, 2009).

While the overall instructional results are positive, results from this study are aligned with other previous studies, in that alternative conceptions of the day and night cycle exist beyond the early childhood period. Küçüközer & Bostan’s (2010) study with kindergarten children found a few children claiming supernatural forces as being responsible for the day and night cycle or providing egocentric or functional explanations in that the night is for sleep and day is for work or school. Similar to Vosniadou & Brewer’s (1994) findings, many children in the current study were unaware that the moon is observable during the day. Looking to older students, Baxter (1989) examined nine to sixteen year olds’ ideas about the day and night cycle in England and found even some of these older children attribute the clouds covering the sun as causing the day and night cycle. Baxter’s findings indicate that the movement of the sun in the sky continues to be a popular explanation among older elementary children and teens. Likewise, the movement of the sun and blocking by clouds were the most common alternative explanations found among Australian children (Siegal, Butterworth, & Newcombe,
In more recent literature, the movement of the sun around the earth or behind the moon were other common elementary age (grade three to grade six) explanations for the day and night cycle (Tao, Oliver & Venville, 2012). These alternative conceptions appear to be a synthesis of scientific information provided in school with students’ own intuitive ideas based on their observational knowledge. As shown here to have positive impacts, providing young children with opportunities to make observations in nature, compare those to textual or digital content, and then share and reflect on these observations may serve to create a stronger foundation for scientific mental models into their elementary school years.

**Implications for classroom practice**

The descriptions of children’s understanding of the day and night cycles provided by this study may lead to more effective curriculum and teaching strategies for our youngest learners. Preschool science content standards suggest that young children should be able to describe qualitative changes in the day and night skies (e.g. Early Learning Content Standards of Ohio). Children also are expected to provide evidence for their reasonings (e.g., how do you know it is a day sky?). Since celestial objects appear in many books for young children and many young children are aware of these celestial objects, early childhood educators may assume that young children already have made connections between objects in the sky and the time of day of observation. However, findings of the current study suggest that while young children understand and can make observations of the sky and celestial objects, (sun, moon and stars) providing evidence for their understanding did not come naturally. Pre instruction, many of the children
pointed to ego-centric reasonings for how they knew it was day, post-instruction, and after being often prompted to explain their reasonings outside of their own actions/lives, the children were better able to provide evidence for their scientific understandings. For example, the young children in this study often associated the moon with ‘nap-time’, which occurs during the day, or the sun with day “because I am awake”. Based on the findings of the present study I offer the strategy of play-based pedagogies in promoting children’s conceptual understanding of the day and night cycle and objects in the sky in early childhood classrooms as a positive and developmentally appropriate way for young children to engage with science.

Young children are intrigued by objects in the sky, and often incorporate celestial objects into their imaginative play. Instructional interventions that involve play and are based on the academic content standards as described here can assist children in focusing their attention on observable properties of the day and night skies and objects visible in the sky. Consequently, developmentally appropriate instruction might promote preschoolers’ understanding of celestial objects towards a more scientific model. Instructional interventions that synthesize play-based pedagogy with inquiry-based learning have potential for helping young children develop understandings of developmentally appropriate space science concepts.

The connection of play with conceptual change theory may provide a rich new area for both children and science education researchers. These two theories can provide many insights into each other and may help researchers understand the future possibilities for play when promoting conceptual change with young children. We know play
provides young children with rich discussion opportunities that improve students’ feelings of success, which may lead to improved student scientific understandings and conceptual change (Bruning, Schraw, & Ronning, 1999; Scott, Asoko, & Driver, 1991). While the work of building the overlap between conceptual understandings, observational knowledge and play is in its initial stages, I hope to bring further empirical evidence to the research base in future studies.
References


Chapter 3
Promoting Conceptual Change Using an Inquiry-Based Professional Development with In-Service Preschool Teachers

Abstract

Improving early childhood teacher preparation and ongoing professional development has been “an urgent priority” for decades (NAEYC, 2002). Beyond general preparation, early childhood teachers’ education and training to teach children science may be even more problematic. A large body of research on both student and teachers’ ideas of astronomy indicates that their understandings can be different from the scientifically accepted norms (Kucukozer & Bostan, 2010; Lelliott & Rollnick, 2010; Stahly, Krockover & Shepardson, 1999). Four early childhood teachers participated in 12 hours of an inquiry-based professional development (PD) built on Physics by Inquiry (McDermott, 1996). All four teachers participated in videotaped pre- and post-interviews to identify their conceptual understandings of astronomy concepts. Two of these teachers were followed into their classrooms to access the efficacy of their instructional implementation with preschool children. Data sources included audio and video files, field notes and interview transcripts. Case studies of the teachers’ conceptual understanding of astronomy concepts before and after the professional development are presented. Following the case studies, findings from the classroom observations are
presented, in which three major categories emerged from the observations: planning, questioning and assessment. Conceptual understanding gains were seen with all four participants when examining standards for grade school (grades K-2). Gains were smaller than expected when examining the teachers’ conceptual understandings of the cause of moon phases, a middle school standard (NGSS, 2013).

**Introduction**

A large body of research on young children’s ideas of astronomy indicates that their understandings can be different from the scientifically accepted norms (Kucukozer & Bostan, 2010; Lelliott & Rollnick, 2010; Stahly, Krockover & Shepardson, 1999). Similarly, teachers often hold the same alternative conceptions as children about astronomy concepts and through their teachings, they can actually perpetuate the cycle of alternative conceptions (Lewis & Linn, 1994; Trundle, Atwood & Christopher, 2002, 2004).

Astronomy concepts are included in the National Science Education Standards (NRC, 1996), *A Framework for K–12 Science Standards: Practices, Crosscutting Concepts, and Core Ideas* (NRC, 2012), the Next Generation Science Standards (NGSS, 2013), as well as state science standards for preschool (Saçkes, Trundle, & Flevares, 2009). Previous studies identified alternative astronomy conceptions among elementary teachers (Atwood & Atwood, 1995; Schoon, 1995), yet relatively few studies focused on the conceptual changes in teachers’ understanding after an instructional intervention (Bulunuz & Jarrett, 2009; Trundle et al., 2002 and 2007b). However, gains have been
reported in pre-service elementary teachers’ conceptions of day and night (Atwood & Atwood, 1997) as well as lunar concepts after inquiry-based instruction (Trundle et al., 2007b). Although previous research included elementary and early childhood teachers’ understandings of astronomy concepts, no previous research has focused exclusively on preschool teachers. The current study addressed this research need by describing in-service preschool teachers’ conceptual change through an inquiry-based professional development. Not only is this study interested in the teachers’ understandings but also how their knowledge transferred into their classroom practices.

**Science content and confidence among preschool teachers**

Improving early childhood teacher preparation and ongoing professional development has been “an urgent priority” for decades (NAEYC, 2002). Beyond general preparation, early childhood teachers’ education and training to teach children science may be even more problematic. The majority of early childhood teachers have very little science content training (Appleton, 2003; Fleer & Robbins, 2003). As a general result, science content knowledge is low and there is a reported lack of confidence in both the teachers’ science content knowledge and science content pedagogies (Fensham, 1991; Garbett, 2003). According to the 2012 National Survey of Science and Mathematics Education, very few early childhood teachers have college or graduate degrees in science or science education but instead have experienced a more traditional generalist teacher preparation program (Banilower, Smith, Weiss, Malzahn, Campbell, & Weis, 2013). Many of these early childhood teacher preparation programs are still largely made of
traditional class formats. These formats consist of a limited number of lecture-oriented science courses typically offering little opportunity for authentic inquiry, experimentation or hands-on learning. These courses fail to model for our teachers what we hope to see them later implement in their own classrooms - inquiry based science (Michaels, Shouse, & Schweingruber, 2008; Nowicki, Sullivan-Watts, Shim, Young, & Pockalny, 2012).

Even when provided a validated ‘high-quality’ curriculum, early childhood teachers are not likely to implement them effectively or with fidelity (Pianta, Howes, Burchinal, Bryant, Clifford, Early, & Barbarin 2005). This stems from the lack of both content knowledge and subject matter confidence (Pianta et al, 2005). Early childhood educators have been “generally characterized by inadequate preparation and offered inadequate ongoing professional development, these teachers generally have few years of experience, and see high turnover rates” (National Research Council [NRC], 2005, p 16). Conversely, preschool teachers have indicated that well-designed professional development experiences enhanced their abilities to learn science concepts, and the experiences improved their teaching practices (Katz, 1999). Well-designed and effectively implemented professional development experiences can lead to improved program quality in preschool (National Research Council [NRC], 2001; National Institute for Early Education Research [NIEER], 2010). Despite the lack of teachers’ science training and low efficacy in their science implementations, young children’s interest in science initially is strong (Cummings, 2003; Fleer & Robbins, 2003). Early childhood specialists and science educators agree that science is a natural fit with the way young children play, engage, explore and try to construct explanations of their environments.
The professional development provided in this study had a purposeful focus on inquiry learning to improve teachers’ conceptual understanding of space science subject matter knowledge. Research in professional development indicates that carefully designed programs are teacher-driven (Borko & Putnam, 1995; Little & McLaughlin, 1993; Tilleman & Imants, 1995); focused on the learning needs of students (Howey & Collinson, 1995; Little, 2006; Pink & Hyde, 1992); school-based (Hawley & Valli, 1999; Little, 2006); long-term and sustained with follow-up support for successful classroom implementation (Hodges, 1996); sensitive to specific classroom needs and contexts for the participating educators (Pink & Hyde, 1992; Schein, 2004); and part of a comprehensive change process that allows educators to practice what they learn in small increments (Guskey, 1995; Little & McLaughlin, 1993). In addition, the professional development program in this study sought to expand teachers’ professional knowledge base including their subject matter knowledge, pedagogical content knowledge, beliefs, and habits (Borko, 2004; Borko & Putnam, 1995).

As mentioned above, the PD included a purposeful focus on inquiry. Inquiry-based instructional strategies include the diverse ways that scientists study the natural world or patterns in data and use evidence to propose explanations about it. The Next Generation Science Standards (NGSS, 2013), as well as other professional education organizations and educational researchers, support the preferential use of inquiry and problem-solving teaching and learning styles in science classrooms (NRC, 2012; NGSS, 2013; NAEYC, 2009). Inquiry learning in science classrooms engages the natural curiosity of students, encourages play, questions, and includes gathering evidence and
student reflection. Students use observational data to propose possible explanations and communicate results to their community.

**Purpose of the Study**

The first research goal was to examine preschool teachers’ conceptual understandings about the day and night skies and patterns in and cause of lunar phases both before and after an inquiry-based PD, which integrated technology. The second research goal in the current study sought to understand the efficacy of the teachers’ instructional interventions with preschool children. Case studies are presented from the four teacher participants, including an analysis of the group as a whole, followed by a discussion of the findings from the classroom observations.

**Methods**

**Case Study**

This qualitative study describes how a group of four in-service early childhood teachers experienced change in both group and individual conceptual understandings, instructional strategies, inquiry strategies and questioning techniques with young learners over time using a case study approach. The methodological approach of this study is based on “description, interpretation” and “identification” of recurrent patterns in the form of themes” (Merriam, 1998, p. 12). Cases are presented from four teacher participants within the contexts of individual teacher classrooms and a teacher professional development course. Several methods of data collection were utilized to document the cases, which were constructed using multiple data points and artifacts used for triangulation. The purpose of collecting these data was to gain understanding of the
teachers’ conceptual understanding of astronomy concepts at different points in time, the experiences within the PD, and the practices and attitudes of the participants in their own classrooms.

**Context and Participants**

The research was conducted with in-service teachers in a large Midwest city and the PD took place at a major research university. Ten teachers completed 12 hours of PD, and four volunteered to participate in the research study and classroom implementation. The four participating teachers taught two age groups of children, 2- and 3-year olds and 4- and 5-year olds. We used a stratified random selection to assign the classrooms to the treatments, resulting in each age group (ages two/three and four/five) having treatment and control groups.

All four teacher-participants were female and held bachelor’s degrees from four-year universities with teacher credentialing programs. Three teachers majored in early childhood education and the other teacher majored in general studies with a specialization in elementary education. Two of the participants have over 25 years experience, while the other two participants each had less than six years of teaching experience.

The classroom implementation occurred at two different school sites, both owned and operated by the same early childhood organization. These year-round schools accepted children ages 18 months to 5 years. Both schools operated in urban settings and accepted publicly funded childcare support. At the first school site (School A), 95% of the enrolled students receive public assistance, and in the second school (School B), 80%
of the children receive financial support, indicating high poverty levels at both school sites.

**Professional Development**

Professional development instruction was from *Physics by Inquiry* (McDermott, 1996) and used guided inquiry investigations. These materials were designed to teach elementary teachers science content through inquiry-based investigations. *Starry Night* planetarium software from Imaginova was integrated into the instruction and allowed teachers to explore celestial objects, including the moon and its phases, and to gather lunar data (Trundle & Bell, 2010).

During the PD, teachers were asked to make observations of the day and night skies, and to provide scientific evidence for the time of day (e.g., color/brightness of sky, objects observed in sky). Participants used their observations to compare the day and night skies. Preschool appropriate literature was incorporated in the instruction to provide additional examples of artists’ representations of day and night skies. The PD also included lunar data gathering and analysis. Specific process skills, such as collecting lunar observation data, recording data, and analyzing lunar data, were modeled and used by the teachers. The teachers collected one month of lunar data using the software and the instructor provided a second month of data for their use in analysis. The lunar data included the moon disk illumination, the direction of the moon’s location in the sky, the time of observation, and angular separation between the sun and moon. Lunar data analysis began after the data-gathering period and included five tasks, including identifying moon shapes and patterns, determining the length of a lunar cycle, sequencing
observed shapes, applying scientific labels and concepts to the shapes of the moon, and modeling the cause of moon phases. From previous research, similar instruction was determined to be effective in helping pre-service and in-service elementary and early childhood teachers construct a scientific understanding of the shape, sequence and cause of moon phases (Trundle et al., 2002, 2006, 2007b).

Targeted concepts by grade level were used from the Next Generation Science Standards (NGSS, 2013). Teachers’ understandings were compared across the grade levels. The preschool standards for Ohio are identifying objects in the sky and providing evidence for day and night. The kindergarten standard focuses on identifying the time of day when the sun, moon, and stars can be observed. Second grade standards call for understandings of the apparent motion of the sun, moon, and stars across the sky, and how the moon appears to change throughout the month (e.g. shapes and sequences). The instruction focused on all of the above concepts, plus the cause of moon phases, which is a targeted concept in middle school (MS-ESS1-1; NGSS, 2013).

Data Gathering

Multiple data sources were used to access the participants’ understandings of targeted astronomy concepts. Data were collected during a pre-instruction interview using a protocol with eight tasks (Table 1) developed by a panel of experts and used in previous research (Trundle et al., 2002, 2006, 2007b). Interviews were conducted both post-PD and post-classroom implementation using the same protocol. During the PD, archival data were collected from teachers’ lunar calendars, drawings, and written responses.
Table 2  
Teacher Interview Protocol of Astronomy Concepts

<table>
<thead>
<tr>
<th>Task</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task 1</td>
<td>Time of day based on sky observations during the interview, evidence of the time of day, objects observed during day and night skies, and color of sky during day and night (verbal responses)</td>
</tr>
<tr>
<td>Task 2</td>
<td>Time of day when celestial bodies (e.g. moon, sun, stars) are observable (verbal responses)</td>
</tr>
<tr>
<td>Task 3</td>
<td>Apparent motion of sun, moon, stars (verbal responses with digital image)</td>
</tr>
<tr>
<td>Task 4</td>
<td>Shape of phases of the moon (drawings)</td>
</tr>
<tr>
<td>Task 5</td>
<td>Patterns of moon shapes (waxing, waning) (drawings)</td>
</tr>
<tr>
<td>Task 6</td>
<td>Cause of moon phases (verbal responses)</td>
</tr>
<tr>
<td>Task 7</td>
<td>Cause of moon phases (verbal responses with 3-D models)</td>
</tr>
<tr>
<td>Task 8</td>
<td>Observable sequences (card sort)</td>
</tr>
</tbody>
</table>

During the classroom implementation, the teacher-participants taught in their own self-contained classrooms while researchers took field notes and videotaped class sessions. Elements of rigor consisted of prolonged engagements with the participants over the course of the PD and in the participant classrooms, member checking on behalf of the research team and triangulation of multiple data sources and data analysis (Guba & Lincoln, 1994).
Qualitative Data Analysis

The videotaped teacher interviews were transcribed, coded, and analyzed to answer the research questions. Initially, the PI and key personnel members of the research team independently analyzed and coded the participants’ responses, using a coding sheet based on previous research (Trundle et al., 2002; 2007b). The coding sheet facilitated analysis of participant answers and helped standardize coding across researchers (Coffey & Atkinson, 1996). Participants’ responses were coded as understandings consistent with a scientific understanding or as being consistent with an alternative conception (Hewson & Hewson, 1983). The members of the research team met regularly to calibrate analyses and to confirm inter-rater agreement. When a discrepancy arose between individual analyses, members reviewed the responses together, discussed the discrepancies in coding, and reached consensus on the categorization. The codes described below were used during the coding process. No new codes emerged from the participant interviews with this group of teacher participants.

After the coding was completed, participants’ responses were individually examined to categorize participants’ conceptual understanding in each of the targeted areas. The six previously developed categories for types of conceptual understanding were used: scientific, scientific fragments, scientific fragments with alternative fragment, alternative, and alternative fragments (see Table 2) (Trundle et. al, 2007b). During categorization, participants’ responses were labeled according to the appropriate conceptual categories and additional analyses were performed to examine if different patterns or combinations of alternative and scientific conceptual understanding emerged from this group.
The constant comparative method was used to analyze the data (Glazer, 1965; Glazer & Strauss, 1967; Strauss & Corbin, 1994; Trundle et al., 2002, 2006, 2007b). This process allowed for qualitative data to be collected, analyzed, and coded in a continual process to look for gaps, omissions, and inconsistencies in the data (Glazer, 1965). According to Glazer (1965, p. 438), “the constant comparative method is concerned with generating and plausibly suggesting (not provisionally testing) many properties and hypotheses about a general phenomenon.” Constant comparative analysis is essentially a method for exploring and illustrating a phenomenon.

A framework from previous astronomy studies was used to code the data (Table 2, Trundle et al., 2007b). The framework allowed researchers to code participant responses as either scientific or alternative. While not occurring in the current study, the nature of the framework and the constant comparative method allows for alternative mental models, not yet identified, to emerge from the data. Participants’ responses were compared to scientific norms of the targeted astronomy concepts to describe participant understanding. Additionally, the analysis allowed researchers to view the teacher participants understandings over time (pre to post), characterize participants overall conceptual understanding, and identify conceptual change (Uçar, 2007). Similar analysis methods have been used in other science education conceptual change studies and across content areas including the particulate nature of matter (Adadan, Trundle, & Irving, 2009), tides (Uçar & Trundle, 2011), and seasons (Wild & Trundle, 2010).
Table 3
*Qualitative Codes Explained (Trundle et al., 2007b)*

<table>
<thead>
<tr>
<th>Code</th>
<th>Meaning of Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>SciOrb</td>
<td>The moon orbits the earth</td>
</tr>
<tr>
<td>SciHalf</td>
<td>Half of moon toward the sun is illuminated</td>
</tr>
<tr>
<td>SciSee</td>
<td>Phase is determined by which part of the illuminated half we can see</td>
</tr>
<tr>
<td>SciEMS</td>
<td>The relative positioning of earth, moon and sun determine the part of the moon we see.</td>
</tr>
<tr>
<td>AltEcl</td>
<td>The dark part of moon is caused by earth’s shadow; or phases are caused by earth’s shadow.</td>
</tr>
<tr>
<td>AltRot</td>
<td>Phases of the moon are caused by earth’s rotation on axis</td>
</tr>
<tr>
<td>AltOth</td>
<td>Other reason; any other than the above given.</td>
</tr>
<tr>
<td>AltETilt</td>
<td>Moon phases caused by tilt of the earth on its axis</td>
</tr>
<tr>
<td>AltGeo</td>
<td>A viewer’s geographic position on earth causes moon phases, people at different locations experience different moon phases.</td>
</tr>
</tbody>
</table>

**Findings**

The goal of the first research question was to explore preschool teachers’ conceptual understandings about the day and night skies, patterns in and cause of lunar phases before and after an inquiry-based professional development. The second research question examined the efficacy of the teachers’ instructional interventions with preschool children.
Research Question 1

Observations, surveys, interviews and participant artifacts provided a broad picture of the case-study participants’ conceptual understanding over the course of the PD and study. Tables 3 and 4 summarize the individual teacher participants’ pre- and post-interview results for the targeted concepts. Further explanations and essential elements of each participant’s understanding are elaborated upon in the four case studies presented below. Following the case studies, other emergent themes or participant understandings from the whole group are presented.

The teachers’ conceptual understandings were assigned into the following six major categories: “scientific”, “scientific fragments”, “scientific fragments with an alternative”, “alternative”, “alternative fragments”, and “no conceptual understanding” (Trundle, 2007b). Four critical elements were required in order for a response to be categorized as reflecting a scientific understanding; these elements are the first four codes in Table 2. However, teachers’ conceptual understandings could not be categorized as scientific if their responses simply included all four of these criteria; responses also had to be devoid of any alternative conceptions. If a participant met some, but not all four, of the scientific criteria, the participant’s response was categorized as scientific fragments. Previous research has indicated that teachers and students can have fragmented scientific models of the cause of moon phases and the sequence of moon shapes (Trundle et al., 2002, 2006, 2007a, 2007b). Participants’ responses were categorized as scientific fragments with alternative fragment(s) if they held some scientific conceptions along with alternative conceptions. In-service teachers’ responses were categorized as
alternative if they did not include any scientific evidence and if they tried to explain moon phases using a model that was not consistent with scientific explanations. Alternative conceptions are models that differ from the scientific model (Vosniadou, 1991). Learners may develop alternative conceptions naturally through their every day experiences (Vosniadou & Brewer, 1992, 1994) or through instruction. Responses were categorized as alternative fragments if they concurrently included multiple alternative conceptions.

Table 3 presents the participant understandings both pre- and post-PD to the concepts they implemented in their own classrooms, the PD concepts were selected from both state and NGSS standards for pre-kindergarten and kindergarten. We would expect young learners in preschool to have understands of these concepts after instruction. Such concepts include, 'looking out the window right now, is it day or night?', 'how do you know it is day' or being able to provide evidence for day, identifying the color of the day and night skies, and when celestial objects are able to be seen in the sky. A code of “Sci” means the teacher participant’s understanding was aligned with the scientific response for that particular question. A code of “Alt” indicates the teacher’s understanding differs from the scientifically accepted answer and is therefore labeled as alternative. As can be seen in table 3, the teachers started with a understandings of most of the pre-k and kindergarten concepts. With the exception of Wyn and Yara, who believed the moon was only visible at night. Further discussion of the individual results and the observed conceptual changes are further discussed in the four case studies below.
Table 4
Results Day/Night and Time of Day (PreK and Kindergarten Standards)

<table>
<thead>
<tr>
<th>Concept/Task</th>
<th>Van</th>
<th>Wyn</th>
<th>Yara</th>
<th>Zoe</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre/Post</td>
<td>Pre/Post</td>
<td>Pre/Post</td>
<td>Pre/Post</td>
</tr>
<tr>
<td>Time moon can be observed</td>
<td>Sci/Sci</td>
<td>Alt/Sci</td>
<td>Alt/Alt</td>
<td>Sci/Sci</td>
</tr>
<tr>
<td>Time observe sun, moon, and stars</td>
<td>Sci/Sci</td>
<td>Alt/Sci</td>
<td>Alt/Alt</td>
<td>Sci/Sci</td>
</tr>
</tbody>
</table>

Table 4 presents a categorization of the participants’ conceptual understandings of the shapes and sequences (both elementary age standards) and the cause of moon phases, a middle school standard (NGSS, 2013). In coding the shapes and sequences portion of the participant interviews, participant answers were compared to the scientifically accepted norms. If the participant understandings were in agreement with the scientific norms, the understandings were coded as “Sci”. If the participant understanding was not in alignment with the scientifically accepted understanding her conception was labeled.
“Alt” for alternative. The coding for conceptual understanding of the cause of moon phases is referenced in Table 2 above. As previously noted, participants can concurrently hold multiple models of understanding, as seen in Table 4 where participants have multiple codes.

Table 5
Shape and Sequences (EC Standards) and Cause of Moon Phases (MS Standards)

<table>
<thead>
<tr>
<th>Participant</th>
<th>Shape</th>
<th>Sequence</th>
<th>Cause of Moon Phases</th>
<th>Cause of Moon Phases</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>Van</td>
<td>Alt</td>
<td>Sci</td>
<td>Alt</td>
<td>Sci</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>AltEclipse</td>
<td>AltEcl(SciOrb,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(SciOrb) SciEMS, SciHalf)</td>
</tr>
<tr>
<td>Wyn</td>
<td>Alt</td>
<td>Sci</td>
<td>Alt</td>
<td>Sci</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>AltEclipse</td>
<td>AltEcl (SciOrb,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(SciOrb) SciEMS)</td>
</tr>
<tr>
<td>Yara</td>
<td>Alt</td>
<td>Sci</td>
<td>Alt</td>
<td>Sci</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>AltFfrags</td>
<td>AltFfrags (SciOrb)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(SciOrb)</td>
</tr>
<tr>
<td>Zoe</td>
<td>Alt</td>
<td>Alt</td>
<td>Alt</td>
<td>Alt</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>AltFfrags</td>
<td>AltFfrags (SciOrb)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(SciOrb)</td>
</tr>
</tbody>
</table>

Case study participant 1: Van.

Van is one of the more experienced teachers of the group, having over 25 years of experience. She is employed at School B and holds a general studies degree with a focus in elementary education. Pre-PD she understood the properties of day and night and could provide evidence for day and night. She also had a scientific understanding of the
times of day/night and when the sun, moon and stars could be observed. Pre-instruction Van held alternative conceptions of the moon shapes, sequences and the cause of moon phases. She held an alternative eclipse model for the cause of moon phases, meaning she believed the dark part of the moon was caused by the Earth’s shadow, however, her explanation of her alternative model was concise. In contrast, even though she held this alternative conception, she understood the moon orbits Earth.

Post-PD, Van appeared to show the greatest improvement in overall conceptual understanding. She held her scientific understandings of the properties of day/night and observation times of objects in the sky (sun, moon, stars). She improved her understandings of moon shapes and sequences to scientific. Although her overall conception of the cause of moon phases was unchanged, she added scientific fragments to her alternative eclipse model. Post-PD she understood the relative positions of the Earth, moon and Sun, that half of the moon is always illuminated except during a rare lunar eclipse, and maintained her understanding the moon orbits Earth. Ultimately, Van had a synthetic model because she added scientific fragments from the PD instruction.

**Case study participant 2: Wyn.**

Wyn, a teacher at School B, has less than six years teaching experience. She has a bachelor of science in elementary education. Pre-PD Wyn’s only scientific understanding was of the properties of day and night and providing evidence for day and night. She had an alternative conception for observation times, believing the moon was only visible at night. She held alternative conceptions for moon shapes, sequences and
the cause of moon phases. Like Van, from our first case study, Wyn had a clearly defined alternative eclipse model, yet understood the moon orbited Earth.

Post-PD Wyn reached a scientific understanding of all the targeted concepts except, the cause of moon phases. She gained understanding of the observation times of the moon, moving her conception to scientific. She also moved to a scientific understanding of lunar shapes and sequences. While she was consistent in her alternative eclipse model belief, she did add scientific fragments to her understanding. She maintained her conception of the moon orbiting Earth and added understanding of the relative positions of the Earth, moon and Sun. Wyn’s post-PD conceptual model, like that of the other participants, is also labeled synthetic due to the nature of her maintaining her alternative conceptions yet adding scientific conceptions from instruction.

**Case study participant 3: Yara.**

Yara teaches at School A, has over 25 years classroom experience and holds a bachelor of science in elementary education. Like Wyn, Yara’s only scientific understanding pre-instruction was knowing the properties of day and night and being able to provide evidence for day and night. Yara believed the moon was only visible at night, giving her an alternative conception of observation time of objects in the sky. She also had alternative conceptions for moon shapes, sequences and the cause of moon phases. Yara’s explanation of the cause of moon phases was neither succinct nor concise and was classified as alternative fragments, meaning she held multiple alternative conceptual understandings within her framework. However, she too understood the moon orbits Earth.
Post-PD Yara’s conceptions of the moon’s shapes and sequences improved and were classified as scientific. She maintained her scientific understanding of the preschool standard, properties and evidence of day/night. However, she maintained her alternative conception of the moon being only visible at night. Yara’s model of the cause of moon phases was resistant to change. She maintained her multiple alternative fragments model, yet failed to incorporate any other scientific fragments from the instruction. She maintained her understanding of the moon’s orbit.

**Case study participant 4: Zoe.**

Zoe, a teacher at School A, holds a bachelor of science in elementary education and has less than six years teaching experience. Pre-PD Zoe had a scientific understanding of both the preschool and kindergarten standards, properties and evidence of day/night and observation times of the sun, moon and stars. She held alternative models of lunar shapes, sequences and the cause of moon phases. Like the other teacher participants, Zoe did understand the moon’s orbit. Zoe’s pre-instruction model for the cause of moon phases was disorderly and not concise, similar to participant 3, Yara. She held multiple alternative conceptions, meaning her overall framework was identified as alternative fragments.

None of Zoe’s conceptual understandings changed with the PD instruction. She maintained scientific understandings of the preschool and kindergarten concepts and alternative conceptions of shapes and sequences. Similarly, her model of the cause of moon phases, which incorporated multiple alternative explanations, was resistant to
change. While she did retain her scientific understanding of the moon’s orbit, she did not add any other scientific fragments from instruction.

**Summary of results**

Prior to the PD, all teachers understood the targeted concepts they were expected to teach in preschool, including observable differences of day and night skies. Two teachers, Van and Zoe, understood the times of day the sun (day), moon (day or night), and stars (night) could be observed, and those who held a alternative conception (Wyn and Yara) believed the moon could only be observed at night. However, none of the teachers had a scientific understanding of the shapes and sequences of moon phases, concepts that are targeted in second grade. Although none of the teachers understood the cause of moon phases, a middle school standard, they all understood that the moon orbits the earth.

Post-PD, all teachers maintained their understandings of the preschool concepts of observable differences of day and night skies. Three of the teachers, Van, Wyn and Zoe, understood the times of day the sun (day), moon (day or night), and stars (night) could be observed, with Wyn improving her understanding of when the moon can be observed, and Yara maintaining her alternative conception that the moon could only be observed at night. Van, Wyn and Yara developed a scientific understanding of moon shapes and sequences, while Zoe maintained her alternative conceptions. While all of the teachers maintained their alternative conceptions of the cause of moon phases, Van and Wyn developed synthetic models and included additional scientific fragments within their alternative models. Both Van and Wyn understood that the relative positions of the sun,
moon, and earth cause moon phases, and they were able to accurately position the models for each of the targeted moon phases. However, their beliefs persisted that the earth’s shadow, or an eclipse, causes moon phases.

**Research Question 2**

The goal of the second research question was to observe the efficacy of the teachers’ instructional interventions with preschool children. Two of the four teachers were followed into the classroom to observe the efficacy of their implementation with preschool learners. This section features elements of the teachers’ classroom practices during the observed implementation regarding planning, questioning and assessment during play-based inquiry instructional sequences. When enacted in best form, inquiry learning engages the natural curiosity of students, encourages play, questions, and includes gathering evidence and student reflection. Students are able to use observational data to propose possible explanations and communicate results to their community. These categories were considered essential components of teaching and learning through inquiry in the preschool classroom. Planning for instruction and assessment revealed the degree to which the teachers were aware of the needs of their young learners. In addition, productive questioning strategies (Harlen, 2001) and providing alternate learning activities surfaced in both of the observed classrooms. The classroom approaches observed were modeled and discussed throughout the teacher PD.

The classroom implementation, included guided science instruction and integrated play using the learning Cycle for preschool science, took place over six school days (Figure 4; Trundle & Smith, in press). The cycle begins with play and allows the
students to explore concepts and materials in a variety of ways. The cycle also provides opportunities for students to discuss and debrief about what they have discovered and the take-aways from each lesson. Each cycle included instructional objectives, were child centered, and incorporated children’s interests, emergent from their free-choice play.

Figure 6. The Preschool Learning Cycle for Science (Trundle & Smith, in press)

**Planning**

Inquiry science lessons engage the natural curiosity of students and encourage play with materials. The teachers were able to respond to children’s interests in the provided materials for day and night play. For example, children were engaging with daytime animals and a camping scene in the dramatic play area. While handled differently by each teacher, both were able to adjust their planning, or utilize interactive planning. This on-the-fly adjusting or monitoring of instruction during class occurred as
teachers modified instruction to maximize student involvement and learning. The teachers led book talks, observations in nature, observations using technology, and hands-on experiences with day and night play materials. The teachers employed multiple modalities during instruction to facilitate learning for all students. Assisting or manipulating equipment (e.g. clipboards, paper, colored pencils) and materials during investigations and play activities addressed the needs of all learners.

**Questioning**

The teacher participants were observed continually asking questions that stemmed from or built on the children’s own ideas and curiosity. Both teachers additionally incorporated questions they overheard which were made by the young learners during their implicit learning and play. The teachers shifted the focus from implicit to explicit by building on the children’s interests and to focus the children’s attention on the objects or phenomena at hand. For example, one teacher participant, when starting a lesson on comparing evidence for day and night asked, *what color is the sky right now?* Both participants continued their lines of questioning by linking the science concepts back to children’s prior experiences; *what kinds of things do you do in the daytime? What are some things can you see in the sky during the day?* These questions helped focus the children’s attention on specific concepts. The teachers moved from asking questions, to having the children plan, predict, observe, and record data.

**Assessment**

Assessment was an ongoing activity for both of the observed teacher participants. During group discussions, the teachers were gauging student understanding by
questioning, student dialog and student reflections. Also during group time the teachers were assessing if the students could compare and contrast evidence collected in nature to similar evidence that was collected using a technology experience. The teachers listened to the children’s play and one teacher participant noted how the children seemed to understand day and night-time animals would not be friends because they would not be awake to play at the same times. Effective educators are gathering evidence constantly and adjusting instruction accordingly. Beyond answering questions, students in both classrooms were able to use collected observational data to propose possible explanations and communicate results to their peers.

**Discussion and Conclusion**

This study examined in-service early childhood teachers’ development of science content knowledge within the context of a professional development course, which modeled inquiry-based pedagogy. Conclusions are presented drawing upon the results from the research questions, as well as implications for future research.

**Discussion**

The first research question explored preschool teachers’ conceptual understandings about the day and night skies and about patterns in and cause of lunar phases, before and after an inquiry-based professional development. Results demonstrated that the professional development was effective in helping preschool teachers understand basic astronomy concepts. Prior to instruction all participants understood the concepts targeted in preschool standards yet only two teachers (Van and Zoe) understood the kindergarten standards for the time of day a celestial object can be
observed in the sky. Furthermore, prior to the professional development, none of the four teacher-participants held a scientific understanding of the patterns and causes of moon phases. These findings are congruent with previous studies, which demonstrated that pre-service and in-service early childhood teachers tend to have alternative conceptions about space science concepts (Saçkes, Trundle & Krissek, 2011; Trundle & Bell, 2010; Uçar & Trundle, 2011). Their collective scientific understanding of the moon’s orbit prior to instruction is a unique find in this literature base and is much higher than other studies (Trundle, 2007b).

The changes in conceptual understanding from pre- to post-instruction were positive, however new findings emerged from this group of participants being separated from the larger early childhood group. As a group, the four participants made great strides for the concepts derived from the preschool through grade 2 standards (NGSS, 2013). In looking at the middle school standards, the four participants were seemed to be more resilient to restructuring their prior conceptual models of the cause of moon phases than participants in previous studies (Trundle et al., 2002, 2006, 2007b; Trundle, Atwood, Christopher, & Saçkes, 2010; Trundle & Bell, 2010; Sadler, 1987; Targan, 1988; Zeilik, Schau & Mattern, 1999). Previous research has highlighted the connection between participants holding a single, concise alternative model being more likely to restructure their initial framework, like Van and Wyn (both held the alternative eclipse model), who were able to add scientific fragments to their models from the instruction. Participants holding multiple alternative conceptions or non-concise conceptions, like Yara and Zoe, who held multiple alternative fragments, have been found more resistant to restructuring
their conceptual models and/or adding scientific fragments to their understanding (Trundle et. al, 2007b). The conceptual understandings of the teachers were improved overall and the PD intervention was a success as seen by the progress made pre to post PD as well as the observed classroom implementations.

Research that is confined to only preschool teachers is limited. Teachers of young children are often grouped into the elementary (Pre-K-3) or early childhood (Pre-K-6) categories for studies such as this. While results of previous studies indicated that the instructional intervention was successful with a larger group of elementary teachers, the results of the current study indicate that the instruction while still successful with this small group of pre-k teachers, there may be differences to consider when planning professional development with this smaller group within the early childhood community.

The second research question examined the efficacy of the teachers’ instructional interventions with preschool children. Two of the four teachers were observed implementing the age appropriate science standards in their classrooms, and the majority of children improved their understanding of the targeted concepts (Smith, Trundle, & Saçkes, forthcoming). To examine the efficacy of the instruction, we much also discuss the results of the young childrens’ conceptual understanding both before and after the instructional intervention. Like the teacher results, the findings were also promising and showed an overall positive effect on the conceptual understandings of the young children post instruction. From the study reported in chapter 2, (conducted with the young children in the classrooms of the teacher-participants), a Wilcoxon Signed rank test revealed a statistically significant time effect from pre- to post-intervention (z= 2.70, p =
0.007) with a moderately large effect size (r = .41) suggesting children’s conceptual understanding increased from pre- to post-assessment. The median score increased from pretest (Md = 17.7) to posttest (Md = 19.0). A Kruskal-Wallis test revealed a statistically significant difference in the post scores across the age levels and treatment groups (Gp1, n = 7; 2/3 treatment, Gp2, n = 10; 2/3 control, Gp3, n = 13; 4/5 control, Gp4, n = 14; 4/5 treatment), x²(3, n = 44) = 9.3, p = .026. The older treatment group recorded the highest median score (Md = 7.50) the 4/5 control group and the 2/3 treatment group both recorded the same median scores (Md = 6.00), the 2/3 control group recorded the lowest median score (Md = 4.50). Post-instruction more children were able to identify day and night (43% pre to 86% post of 2- and 3-year olds) and provide supporting evidence for the time of day (14% pre to 29% post of 2- and 3-year olds; 36% to 79% post of 4- and 5-year olds) (Smith, Trundle, & Saçkes, forthcoming).

The instructional unit included guided science instruction and integrated play using the learning cycle for preschool science (Figure 4, Trundle & Smith, in press) and took place over six school days. The preschool science learning cycle, builds on the 5-E instructional model (Bybee & NCIS, 1989), begins with play, encourages exploration, and provides opportunities for reflection and conclusions. Each cycle of instruction (play, explore, explain) focused on a different topic: day sky, night sky, and comparisons of the day and night skies. While each cycle included instructional objectives, the lessons were child-centered and incorporated the children’s interests. Both teachers were able to build in dialog to the intentional learning experiences that was emergent from the young children’s free-choice play. The elements of the teachers’ classroom practices regarding
planning, questioning and assessment emerged from the observed inquiry-based instructional sequences in the classroom. When represented in best form, inquiry learning engages the natural inquisitiveness of children, encourages play, questions, and includes gathering evidence and student reflection. The young learners in the teacher participant’s classrooms were able to use their observational data to propose possible explanations and communicate results to their classroom peer community.

This study has limitations, as all case studies do, however, the limited sample size did allow the research team to work intensely with the teacher participants to gain better awareness of their processing, conceptual models and the realities of their classroom implementations.

**Implications**

Although preschool children are not expected to understand sophisticated science concepts, such as the cause of the lunar phases, pre-service and in-service early childhood teachers with alternative conceptions about these concepts present a serious problem for instruction with young children (Saçkes et al., 2011). Teachers’ alternative conceptions may hinder their presentations of basic concepts that lead to the understandings of the observable patterns in celestial objects’ movement and the cause of lunar phases. If early childhood teachers are expected to teach their students the foundational components of space science concepts, it is reasonable to expect teachers to have a scientific understanding beyond what they are required to teach. Without instruction to help in-service teachers develop scientific understandings of basic space science concepts, the
potential exists that they will not recognize any alternative conceptions their students may have about those concepts.

Twelve states have preschool standards, and four have standards directly applicable to this research study regarding the day and night cycle (Saçkes et al., 2009). Preschool teachers have been under-represented in the previous research on elementary teachers’ conception of moon phases. The results of this study indicate that preschool teachers may perform differently than the group of early childhood or elementary teachers as a whole. While this study examines a small population, it is reasonable to predict that many preschool teachers do not understand the patterns, sequences, and cause of moon phases. Teachers cannot effectively teach what they themselves do not understand. Evaluating instructional strategies that address alternative conceptions can thus inform the practice of science teacher educators.

Findings of this study provide preliminary, successful and thought-provoking data about preschool teachers’ understandings of standard-based space science concepts, which requires further attention from researchers. As noted, preschool teachers are often included with the larger group of early childhood or elementary teachers. Depending on state licensure, an early childhood teacher can mean they are licensed to teach grades PreK-3, K-6 or K-8. Given no other studies were found which examined only preschool teachers conceptual understanding of science concepts, I cannot speak to how these results compare to prior research. This does make a clear argument to continue work with in-service preschool teachers. In addition, it also indicates the need for high-quality professional development courses for early childhood teachers which support the process
of change in teachers' thinking and practice with acknowledgement given for the complex, dynamic and responsiveness called for when teaching in the preschool setting.
References


Merriam, S. B. (1998). *Qualitative Research and Case Study Applications in Education. Revised and Expanded from" Case Study Research in Education."*: ERIC.


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Chapter 4


Abstract

The Nature of Solutions and Solubility—Diagnostic Instrument (NSS–DI) developed by Adadan and Savasci (2012) was designed to assess students’ understanding of solution chemistry concepts. The original instrument was developed in Turkish to assess solution chemistry understanding among 16 and 17 year old students. From its original development and implementation the test has been modified to an English version of the instrument, the NSS-DI Eng. To evaluate the reliability and the discriminatory power of this assessment tool, statistical tests were used focusing on both item analysis (item difficulty index, discrimination index, point-biserial coefficient) and the entire test (Cronbach’s alpha and Ferguson’s delta). While the results indicate that the English version of the NSS-DI is a reliable assessment tool, there are also some indications that the instrument could be improved.
Introduction

Solution chemistry is an essential component of an introductory chemistry course because developing an understanding of the associated concepts of solution chemistry supports the learning of more advanced topics such as chemical kinetics, chemical equilibrium, acid–base equilibrium, and electrochemistry (Adadan & Savasci, 2012; Calik, Ayas, & Coll, 2010; Prieto, Blanco, & Rodriguez, 1989). However, past research has consistently revealed that students often develop non-scientific or alternative conceptions of aspects of solution chemistry (Devetak, Vogrinc, & Glazar, 2009; Ebenezer, 2001; Teichert, Tien, Anthony, & Rickey, 2008; among others). These alternative conceptions typically differ from the scientifically accepted views and considerably inhibit further science learning by influencing the way in which students make meaning of the newly introduced concepts (Duit & Treagust, 1995). Alternative conceptions are knowledge that students have actively constructed from their everyday experiences to explain the world around them.

Science teachers typically rely on pencil and paper tests, often comprised of multiple-choice questions, due to the typical constraints of too little time and too many students (Taber, 2001; Treagust, 1995). However, multiple-choice tests have a documented number of limitations including the lack of ability to assess student reasoning and the possibilities of guessing (Ding & Beichner, 2009; Liu, 2010). To minimize these limitations, researchers have developed two-tier multiple-choice diagnostic instruments, “which include items specifically designed for diagnosing students’ alternative conceptions in a limited and clearly defined content area” (Adadan
Within a two-tier multiple-choice test, the first tier items call for a response to content prompts and the second tier calls for the reasoning behind the tier one response, one response provided is an ‘other’ option, which allows students to write down their own understanding if any of the given options do not match their reasoning (Voska & Heikkinen, 2000). Such tests have been found useful for teachers and convenient for students to complete (Liu, 2010; Millar & Hames, 2006; Othman, Treagust, & Chandrasegaran, 2008).

This paper reports on the reliability of the English version of the NSS-DI, as measured by statistical tests focusing both on individual items and on the test as a whole. Test reliability has two features: consistency and discriminatory power (Ding, Chabay, Sherwood & Beichner, 2006; Ding & Beichner, 2009; Ding & Liu, 2012). A test is reliable if it is consistent within itself and over time. If a test is shown to be reliable, one can have confidence that the same students would get the same score if they took the test under the same conditions more than once. In addition, on a reliable test, the score variance is attributed to the variation in the population of test takers; e.g. students whose levels of understanding are different will achieve different test scores. Both of these test reliability aspects can be statistically assessed. A test must also be valid in order to be meaningful. A test is valid if the skills or knowledge it measures are directly relevant to the purported domain of the test. Validity cannot be assessed statistically and is usually determined by the agreement of experts in the field’s domain. Since validity is not assessed statistically, this paper will only briefly address the validity of the NSS-DI Eng,
with a much more detailed account of the statistical analysis related to the instrument’s reliability.

**Objectives**

The purpose of this study is to perform the first psychometric reliability evaluation of The Nature of Solutions and Solubility—Diagnostic Instrument (NSS–DI Eng) and report on the instrument’s reliability. This two-tier multiple-choice instrument includes the various associated aspects of solution chemistry. The NSS-DI was developed and validated in Turkey for identifying Turkish high school students’ conceptions of solution chemistry and differs from other multiple-choice instruments (Pinarbasi, Canpolat, Bayrakceken & Geban, 2006; Uzuntiryaki & Geban, 2005) in that it employs the two-tier format, multiple contexts, multiple modes and levels of representation.

**Framework/Conceptual Model**

The NSS-DI as an evaluation tool is grounded in constructivism. Assessments like the NSS-DI are not substitutes for the role of ongoing teacher assessment. However, this instrument, when in best form, will allow teachers to better understand the vast understandings their students are bringing to instruction. Characteristic to constructivism, students’ existing conceptions play a key role in the outcomes of new learning (Ausubel & Robinson, 1969). Constructivism has three foundational characteristics: (1) learning is an active process, (2) students construct their knowledge by means of their pre-existing knowledge, and (3) a learner is responsible for his/her own learning (Freedman, 1998). Researchers have emphasized that students come to science
classes with a wide range of alternative conceptions about diverse scientific phenomena, and that these alternative conceptions are usually the result from their direct or indirect observation of, and everyday interaction with, the natural world around them (Driver, Squires, Rushworth, & Wood-Robinson, 1994; Vosniadou, 2002). Students each construe the world differently, and while this test may only gather the main conceptions held by a given population, as constructivists we must also realize that these are not the entirety of possible conceptions. Individual differences in experiences, information processing and worldly interactions are infinite and a test such as this can only hope to provide us with greater insight to the more common conceptions, yet never all of the conceptions. Other sources of alternative conceptions may be perpetuated in the classroom through textual misrepresentations, misleading language and teaching itself due to unsuitable instructional materials and the teachers’ conceptions (Adbo & Taber, 2009; Duit & Treagust, 1995; Lin, Cheng, & Lawrenz, 2000). Purposeful science instruction aspires to restructure and/or reorganize students’ alternative conceptions as needed to accommodate scientifically accepted understandings (Smith, Blakeslee, & Anderson, 1993).

Similar to other chemistry concepts, a scientific understanding of the associated solution chemistry concepts entails skills of particle theory of matter in so far that students can make connections between what is actually being observed and the related underlying submicroscopic processes (Adadan & Savasci, 2012; Blanco & Prieto, 1997; Calik et al., 2007; Devetak et al., 2009; Ebenezer, 2001). Because multiple levels of representation (macroscopic, submicroscopic, symbolic) can sometimes express the same
meaning or complement each other by representing the different features of meaning (Cheng & Gilbert, 2009), in the current study, students’ understandings of solution chemistry were challenged in multiple levels of representation. Instruction needs foundational roots of the vast student understandings that are brought to the classroom/instruction.

**Background and Reliability of the Nature of Solutions and Solubility—Diagnostic Instrument (NSS–DI Eng)**

The NSS-DI is a 13-item (two-tiered) multiple-choice test which covers the main solution chemistry topics discussed in both introductory high school chemistry courses and college-level introductory chemistry courses. It was designed for assessing students’ conceptual understanding and subsequent alternative conceptions of solution chemistry concepts. Test items are mainly qualitative, with two quantitative questions, that require simple calculations. All test items are intended to assess students’ understandings and reasonings of basic solution chemistry concepts (Table 5) in an introductory chemistry course (Adadan & Savasci, 2012). The original NSS–DI was developed in Turkey in three phases utilizing the two-tier multiple-choice instrument development procedures proposed by Treagust (1988, 1995). The first phase involved establishing the scope of the relevant content of the instrument. Drawing upon the Turkish high school curriculum objectives concerning solution chemistry and the textbook coverage of the relevant content, knowledge statements about solution chemistry concepts were defined (e.g., ‘Solutions can be classified as unsaturated, saturated, or supersaturated with respect to the solubility of a solute’) (Adadan & Savasci, 2012). Next, a concept map was generated
for the graphical representation of the statements in a connected manner (see Treagust, 1995). A panel of experts, two science education professors and two experienced chemistry teachers, validated the content of the propositional statements and the concept map based on the accuracy and relevance to the Turkish high school chemistry curriculum content (Adadan & Savasci, 2012). The second phase included an examination of the existing research on students’ conceptions of the nature of dissolving and the associated solution chemistry concepts (Calik et al., 2007; Calik, Ayas, & Ebenezer, 2005; Devetak et al., 2009; Ebenezer, 2001; Pinarbasi & Canpolat, 2003, among others). Phase three involved multiple steps concerning the design of the test items and statistical analysis of the final version of the two-tier diagnostic test.

The final version of the Turkish NSS–DI was produced with some revisions from the second version of the NSS-DI instrument. The specific conceptual aspects of solution chemistry addressed by each item can be seen in Table 6 below. Table 6 also provides information about the levels and modes of representation used for each item. This initial Turkish version of the NSS-DI reported reliability by Cronbach's alpha coefficient. The Cronbach’s alpha for the content tier and both tiers were found to be 0.697 and 0.748, respectively. These alpha values are relatively high compared with the values of other two-tier tests in the literature (Caleon & Subramaniam, 2010; Othman et al., 2008; Tan, Goh, Chia, & Treagust, 2002).
Johnstone’s Triangle

Taber (2013) stated, “Much scholarship in chemical education draws upon the model of there being three ‘levels’ at which the teaching and learning of chemistry operates” (p. 156). Alex Johnstone (1991, 2000) illustrated these levels of chemical representations as a triangle with the points labeled as macroscopic, submicroscopic, and symbolic (Figure 7). He posits that this ‘multi-level thought’ requirement is what makes all science difficult for students to understand, but similar to other disciplines with call for coordination between representations, chemistry specifically requires the coordination of (a) the macroscopic and tangible: what can be observed by the senses; (b) the submicroscopic: atoms, molecules, ions and structures; and (c) the symbolic: symbols, formulas, equations, molarity, mathematical manipulation, and graphs (as cited in Taber, 2013, p. 157). The diverse use of representations is maintained in the NSS-DI Eng (Table 6).

![Figure 7. Three Basic Components of Chemistry; macro, submicroscopic and representational chemistry (Johnstone, 1993)](image)

---

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Table 6
Sections of solution chemistry represented on the Nature of Solutions and Solubility—Diagnostic Instrument (NSS–DI Eng)

<table>
<thead>
<tr>
<th>Item number(s)</th>
<th>Sections</th>
<th>Level of Representation *</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a, 1b, 7a, 7b</td>
<td>The nature of solutions and dissolving</td>
<td>M, S</td>
</tr>
<tr>
<td>2a, 2b, 11a, 11b, 13a, 13b</td>
<td>Factors affecting the solubility of solids</td>
<td>M, S, Syb</td>
</tr>
<tr>
<td>6a, 6b, 8a, 8b</td>
<td>Factors affecting the solubility of gases</td>
<td>M, S, Syb</td>
</tr>
<tr>
<td>3a, 3b, 4a, 4b</td>
<td>The types of solutions relative to the solubility of a solute</td>
<td>M, S</td>
</tr>
<tr>
<td>5a, 5b, 10a, 10b, 12a, 12b</td>
<td>Concentration of solutions</td>
<td>M, S</td>
</tr>
<tr>
<td>9a, 9b</td>
<td>The electrical conductivity of solutions</td>
<td>M, S, Syb</td>
</tr>
</tbody>
</table>

*Levels of representation: M, macroscopic; S, submicroscopic; Syb, symbolic

Participants

The NSS-DI Eng was administered to 822 participants enrolled in an introductory college chemistry course at a large state university in a large Midwest city. The instrument was administered at the beginning of the semester, prior to any solution chemistry instruction (Ding, Reay, Lee & Bao, 2008). The assessment was given during
normal class/lab time and took approximately 30 minutes for the participants to complete. A wide variety of majors were represented in the population, however the majority came from the health science field; e.g. biochemistry, biology, pre-medicine. Data were collected during the summer and fall of 2014.

**Data Analysis**

While coding the data in SPSS, student names were replaced with numerical pseudonyms such as ‘HA0606-1610-1’, which represented the student number, ‘HA0606’, along with the chemistry course and section, ‘1610-1’. Students’ responses to each item of the content and reasoning tier of the NSS–DI Eng were scored separately, assigning ‘1’ for each correct and ‘0’ for each incorrect response. The assessment is a 13 question two-tiered assessment, with tier one of each question (e.g. 1a, 2a, 3a, etc.) calling for content knowledge understanding, and tier two of each question (e.g. 1b, 2b, 3b, etc.) calling for students’ reasoning. These 13 two-tiered questions were treated independently as 26 items for the following described statistical analysis. Answering the first tier incorrectly, did not withhold a participant from being scored on the second tier. For example, and as will be seen in the charts below, at times, students were unable to provide a correct response for the content tier, but held a scientific understanding of the reasoning behind the related solution chemistry concept.

Using the data from this combined sample of 822 introductory level college chemistry students, five statistical tests were performed; three measures (item difficulty index, discrimination index, point-biserial coefficient) which focused on the individual items of the test and two measures (Cronbach’s alpha and Ferguson’s delta) which
focused on the test as a whole. In the following sections, each test is described and results are discussed.

**Statistical Analysis**

Concept inventory instruments are commonly evaluated by statistical tests for several features, including item difficulty, item discrimination, and reliability (Ding et al., 2006; Ding & Beichner, 2009; Ding & Liu, 2012).

**Item Difficulty Index**

The item difficulty index ($P$) for a question is calculated as the total number of correct responses ($N_1$) divided by the total number of responses ($N$); accordingly, $P$ is the measure of the difficulty of each question. Many have argued that this may be more appropriately called an “easiness index” (Ding et al., 2006). $P$ scores can range from 0 to 1 and are dependent on the population to which the test was administered. The greater the $P$ value is, the higher the percentage of participants who correctly answered that item and thus the easier the item may be considered within the given population. If $P=0$, then no participants correctly answered the item and conversely if $P=1$ all participants answered the item correctly.

$$P = \frac{N_1}{N}.$$ 

Extremes, like $P = 0$ or $P=1$ are typically avoided in concept inventories or educational assessments. Doran (1980) established the commonly accepted value for the difficulty index value to fall between 0.3 and 0.9, where 0.5 is the optimal value. Item
difficulty is displayed in Table 6 and displayed graphically in Figure 8. In addition, the averaged difficulty index value \( P \) for all test items is frequently used as an indication of the test difficulty (Ding et al., 2006; Ding & Beichner, 2009). The averaged difficulty index \( P \) for the NSS-DI Eng is 0.48, which falls into the acceptable criterion range [0.3 to 0.9].

Figure 8. NSS-DI Eng item difficulty index from a sample of 822 introductory chemistry students. The average difficulty index is 0.48

In looking to Figure 8, one can see where scores within an item (e.g. 7a, 7b) were different. In looking at 7a, the item was lower on the difficulty index scale meaning the item was more difficult in this given population. When examining 7b, the item scored higher on the difficulty index meaning it was easier for this population to correctly answer. So within the population of 822, more of the students were able to provide the correct reasoning for question 7 than were able to accurately provide the correct scientific response to the question. Similar situations are seen for items 10 and 11 (Figure 8).
**Item Discrimination Index**

Item discrimination index \( D \) refers to how well an assessment item differentiates between high and low scorers. In other words, it is a measure of the discriminatory ability of each test item. The possible range of the discrimination index is -1.0 to 1.0; however, an item with a negative discrimination value suggests a problem. When an item is discriminating negatively, the more knowledgeable examinees are generally incorrectly answering the item while the less knowledgeable examinees are correctly answering the item. A negative discrimination index may signal that the particular item is measuring something outside the scope of the assessment, or that the item may have been incorrectly coded.

To calculate the item discrimination index \( D \), the entire sample of students is divided into two different groups of equal size, a high group \( (H) \) and a low group \( (L) \). The groupings are based on whether an individual’s total score is higher or lower than the median total score of the entire sample. For each test item, the number of correct responses in both \( H \) and \( L \) groups are counted \( (NH \) and \( NL) \), where the total number of the students is \( N \).

\[
D = \frac{N_H - N_L}{N/2}.
\]

Different calculations of discrimination index are often employed by educational researchers, of which the most popular are the 50%-50% and the 25%-25%. To calculate the discrimination index for the 26 items on the NSS-DI Eng, the 25%-25% formula was
utilized, meaning the top 25% were used as the high group and the bottom 25% as the low group.

\[ D = \frac{N_H(\text{top 25\%}) - N_L(\text{bottom 25\%})}{N/4} \]

One reason for not employing the 50%-50% calculation is that it can underestimate the discriminatory ability of the items. The 25%-25% calculation, on the other hand, uses the most consistent student scores from the top and bottom scorers. The possible range for the item discrimination index \( D \) is \([-1, +1]\), where +1 is the best value and -1 is the worst value. Extreme values are unlikely, such as \( D = +1 \), meaning all the students in the high group would have correctly answered the item and all students in the low group would have incorrectly answered the item. In the opposite extreme, \( D = -1 \), all the students in the low group would have correctly answered an item while all the high group students would have incorrectly answered the item. As noted above, negative values for discrimination indices indicate problems with that particular item. An item is typically considered to provide good discrimination if \( D \geq 0.3 \) (Ding et al., 2006; Ding & Beichner, 2009; Doran, 1980). It is ideal to have the majority of the test with a relatively high discrimination (e.g. \( D \geq 0.3 \)).
Figure 9. NSS-DI Eng item discrimination index from a sample of 822 introductory chemistry students. The average discrimination index is 0.27.

Figure 9 shows the discrimination index for the items on the NSS-DI Eng. Most of the $D$ values for NSS-DI Eng items vary from 0.1 to 0.5. This shows that most NSS-DI Eng items have somewhat limited discriminatory power. The discriminatory power was higher when looking specifically at items 6 (a,b) and 8 (a,b), which were both about the solubility of gases. The averaged discrimination index for NSS-DI Eng, was also calculated which can be expressed as:

$$
\bar{D} = \frac{1}{K} \sum_{i=1}^{K} D_i.
$$

The average discrimination index (25%-25%) $D$ for NSS-DI Eng was calculated to be 0.27. While this is close to the accepted norm, this average discrimination value does not satisfy the accepted criterion of $D \geq 0.3$ (Ding et al., 2006; Doran, 1980).
When interpreting the value of an item’s discrimination index it is important to be aware that there is a relationship between an item's difficulty index and its discrimination index. If an item has a very high (or very low) P-value, the potential value of the discrimination index will be much less than if the item has a mid-range p-value. Therefore, if an item is either very easy or very hard, it is not likely to be very discriminating. This can be seen below in Table 7, when examining items 5a and 7a. Question 5a was measured as “easy” by its high P value and had a very low discrimination value \(D = 0.05\). Conversely, 7a measured as “highly difficult” for this sample of students, with a difficulty index of \(P = 0.14\) and a low discriminatory value \(D = 0.08\).
<table>
<thead>
<tr>
<th>Item #</th>
<th>P</th>
<th>D NSS-DI Eng</th>
<th>D NSS-DI*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>0.76</td>
<td>0.12</td>
<td>0.48</td>
</tr>
<tr>
<td>1b</td>
<td>0.64</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>2a</td>
<td>0.13</td>
<td>0.17</td>
<td>0.63</td>
</tr>
<tr>
<td>2b</td>
<td>0.21</td>
<td>0.17</td>
<td></td>
</tr>
<tr>
<td>3a</td>
<td>0.48</td>
<td>0.21</td>
<td>0.61</td>
</tr>
<tr>
<td>3b</td>
<td>0.27</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>4a</td>
<td>0.45</td>
<td>0.19</td>
<td>0.41</td>
</tr>
<tr>
<td>4b</td>
<td>0.44</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>5a</td>
<td>0.95</td>
<td>0.05</td>
<td>0.24</td>
</tr>
<tr>
<td>5b</td>
<td>0.74</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>6a</td>
<td>0.61</td>
<td>0.32</td>
<td>0.78</td>
</tr>
<tr>
<td>6b</td>
<td>0.48</td>
<td>0.45</td>
<td></td>
</tr>
<tr>
<td>7a</td>
<td>0.14</td>
<td>0.08</td>
<td>0.41</td>
</tr>
<tr>
<td>7b</td>
<td>0.45</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>8a</td>
<td>0.50</td>
<td>0.50</td>
<td>0.76</td>
</tr>
<tr>
<td>8b</td>
<td>0.46</td>
<td>0.53</td>
<td></td>
</tr>
<tr>
<td>9a</td>
<td>0.53</td>
<td>0.24</td>
<td>0.56</td>
</tr>
<tr>
<td>9b</td>
<td>0.32</td>
<td>0.31</td>
<td></td>
</tr>
<tr>
<td>10a</td>
<td>0.26</td>
<td>0.16</td>
<td>0.41</td>
</tr>
<tr>
<td>10b</td>
<td>0.34</td>
<td>0.39</td>
<td></td>
</tr>
<tr>
<td>11a</td>
<td>0.56</td>
<td>0.47</td>
<td>0.44</td>
</tr>
<tr>
<td>11b</td>
<td>0.77</td>
<td>0.43</td>
<td></td>
</tr>
<tr>
<td>12a</td>
<td>0.68</td>
<td>0.44</td>
<td>0.64</td>
</tr>
<tr>
<td>12b</td>
<td>0.64</td>
<td>0.48</td>
<td></td>
</tr>
<tr>
<td>13a</td>
<td>0.37</td>
<td>0.32</td>
<td>0.61</td>
</tr>
<tr>
<td>13b</td>
<td>0.39</td>
<td>0.29</td>
<td></td>
</tr>
</tbody>
</table>

*values for the reasoning tier were not reported for the original Turkish NSS-DI

**Point Bi-Serial Coefficient (rpbs)**

The Point Bi-serial coefficient is another item-level measure of statistical evaluation. It is a measure of how consistent items are with the entire test, or the strength of association between variables. It is representative of the correlation between students’ scores on an individual item and their scores on the entire test, and is fundamentally a
special case of Pearson’s R correlation measurement. The possible range of this measurement is $[-1, +1]$. “If an item is highly positively correlated with the whole test, then students with high total scores are more likely to answer the item correctly than are students with low total scores” (Ding et al., 2006; Ding & Beichner, 2009). Conversely, a negative value indicates that students with low total scores were the most likely to get a particular item correct and is an indication that the specific test item is problematic.

Under ideal circumstances, all test items should be highly positively correlated with the total score, however that can be unrealistic to some extent for a test consisting of a large number of items/questions (Ding et al., 2006; Ding & Beichner, 2009). The criterion broadly accepted for measuring the “consistency” or “reliability” of a test item is $r_{pbs} \geq 0.2$ (Doran, 1980). Items with a point bi-serial coefficient lower than 0.2 can exist within a test, but such items should be limited in occurrence. The average point biserial coefficient $r_{pbs}$ of all items, $K$, in a test can be calculated. The average point biserial coefficient for NSS-DI Eng is 0.32, which is greater than the accepted criterion value 0.2, so NSS-DI Eng items overall have fairly high correlations with the entire test.

Figure 10 provides the point bi-serial coefficient values for each NSS-DI Eng item. Almost all items have satisfactory $r_{pbs}$ values, indicating that most NSS-DI Eng items are reliable and consistent. We can see that items 1a, 3b, 5a, 7a and 7b are somewhat problematic.
Cronbach’s Alpha

Cronbach's alpha is a measure of internal consistency, or how closely related a set of items is as a group. However, unlike the point bi-serial coefficient, Cronbach’s alpha is a whole test statistic. Cronbach’s alpha is a reliability index and is a necessary condition for validity but is not sufficient on its own. The range of Cronbach’s alpha is [-1, +1]. Cronbach's alpha will generally increase as the inter-correlations among test items increase. Cronbach's alpha is said to indicate the degree to which a set of items measures a single construct. While the test can be run with the same students who take an assessment twice under the same conditions, the assessment in this study was given only once. Cronbach’s alpha is a convenient way to estimate the reliability for a test using item response data from a single test administration (Crocker & Algina, 2006).

Alpha scores are widely accepted if they are $\geq 0.7$. The Cronbach’s alpha for the NSS-DI Eng was calculated to be 0.71. Thus, it is above the accepted criterion value and
it can be inferred that at least 71% of the total score variance is due to the true score variance (Crocker & Algina, 2006).

**Ferguson’s Delta \( \delta \)**

Ferguson’s delta is another whole-test statistic as it is a measure of how strong the test is in separating out the students by total scores, or the score distribution. It is optimal to have a broad distribution in the total scores, as this shows a better discrimination. Ferguson’s delta can be written as (Kline 1986, p 150):

\[
\delta = \frac{N^2 - \sum f_i^2}{N^2 - N^2/(K + 1)},
\]

Where \( N \) is the number of students taking the test, \( M \) is the number of items in the test and \( f_i \) is the frequency of cases with the same score. The possible range of Ferguson’s delta values are [0,1]. If a test has a Ferguson’s delta greater than 0.90, it is considered to provide a good discrimination among students (Kline 1986, p. 144). The measured Ferguson’s Delta for the NSS-DI Eng was \( \delta = 0.97 \).
Table 8

<table>
<thead>
<tr>
<th>Test statistic</th>
<th>Possible values</th>
<th>Desired Values</th>
<th>NSS-DI English</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item difficulty index $P$</td>
<td>$[0, 1]$</td>
<td>$\geq 0.3$</td>
<td>Avg = 0.48</td>
</tr>
<tr>
<td>Item discrimination index $D$</td>
<td>$[-1, 1]$</td>
<td>$\geq 0.3$</td>
<td>Avg = 0.27</td>
</tr>
<tr>
<td>Point bi-serial coefficient $r_{pbs}$</td>
<td>$[-1, 1]$</td>
<td>$\geq 0.2$</td>
<td>Avg = 0.32</td>
</tr>
<tr>
<td>Cronbach’s Alpha reliability index</td>
<td>$[-1, 1]$</td>
<td>$\geq 0.7$</td>
<td>0.71</td>
</tr>
<tr>
<td>Ferguson’s delta</td>
<td>$[0, 1]$</td>
<td>$\geq 0.9$</td>
<td>0.97</td>
</tr>
</tbody>
</table>

Discussion and Conclusions

A goal of this current study was to examine the reliability of the English version of the Nature of Solutions and Solubility—Diagnostic Instrument (NSS–DI), a two-tier diagnostic instrument used to assess students’ understanding of the associated solution chemistry concepts. The results of the study revealed that the two-tier NSS–DI Eng was useful in terms of diagnosing the extent and diversity of students’ ideas about solution chemistry concepts. The reliability and discriminatory power of the NSS–DI Eng was evaluated by five statistical tests, three of which focused on individual items and two of which focused on whole test statistics. The results, which are summarized in Table 8, indicate that the NSS-DI Eng is a reliable test with sufficient discriminatory power.

Consistent with previous research and the Turkish implementation (Adadan & Savasci, 2012; Caleon & Subramaniam, 2010; Othman et al., 2008; Tan et al., 2002; Voska & Heikkinen, 2000), the results indicated that the majority of participants’
performance on the content tier of the test items exceeded their performance on both tiers of the test items. This implies students can recall correct answers to specific concepts but lack the correct reasoning behind such concepts.

The items on the NSS-DI Eng were found to have relatively low discriminatory power in comparison to the Turkish version of the instrument. This finding would suggest that some of the items might need to be altered in the way that they are presented and/or written. For example, many of the American students were confused by the way the answers were presented in item 7a. When comparing the English version (D = .08) to the Turkish version (D = .41) the large differences are easily seen. This could point to the cultural nature of test construction, layout and interpretation. Altering items for language clarity and re-running the study would allow researchers to make comparisons of student responses to item construction.

Other differences that could point to the differences seen in the large differences in item discrimination indexes between the English and the Turkish version could have to do with the test administration itself. The Turkish version was administered to high school students who are expected to stay in a classroom regardless of being finished with a task. In many of the implementations in this study, the college students would rush through the test as (depending on the instructor) they would be allowed to leave early. In addition, there were no incentives nor did it effect the students grades. These factors may have altered how much time and thoughtfulness students put into completion of the instrument.
Implications for Research

The NSS–DI Eng instrument in its current form is a good tool for teachers and researchers to use to assess students’ understanding of solution chemistry. However, attention and/or changes to some of the instrument items could be useful in making the assessment tool even more effective. In the future and upon improvement of the NSS-DI Eng, researchers will be able to identify the scope and features of students’ conceptions and alternative conceptions around the related components of solution chemistry by using the two-tier diagnostic instrument. While such a study has already been carried out in Turkey, collecting data with the English version of the instrument will allow future studies to examine data across cultures. The current and future studies are essential, because even with extensive research on students’ conceptions regarding the nature of dissolving (Calik et al., 2005), there is limited research on students’ conceptions of some of the other conceptual aspects of solution chemistry (e.g., factors affecting solubility of solids and gases, the types of solutions relative to the solubility of a solute, concentration of solutions, and the electrical conductivity of solutions) (Adadan & Savasci, 2012; Calik et al., 2010; Devetak et al., 2009; Teichert et al., 2008). Therefore, future studies could extend this body of research students’ conceptions of the less reported aspects of solution chemistry.

Implications for Practice

The construction of a valid and reliable assessment for use in chemistry classrooms will provide teachers and researchers with both a useful classroom tool and important insights into the minds of their students, specifically regarding the ways in
which students use reasoning to understand concepts related to solution chemistry. In illuminating those understandings, teachers and researchers can identify common alternative conceptions, a process which will allow them to design better instruction that can accommodate and revise alternative conceptions. Future hopes for the NSS-DI Eng are that upon further improvement, it will provide chemistry educators and researchers insights into common solution chemistry conceptions, alternative conceptions, and student understandings, and will lead to improved chemistry education.
References


Cheng, M., & Gilbert, J.K. (2009). Towards a better utilization of diagram in research into the use of representative levels in chemical education. In J.K. Gilbert & D.F. Treagust (Eds.), *Multiple representations in chemical education* (pp. 55–73). Dordrecht: Springer.


Chapter 5

Discussion of the Three Studies

Introduction

While the findings of any study are important, it is critical that a researcher discuss not only the how the data and findings can be used in practice, but also how they inform the future directions of research within the discipline. This final chapter discusses the data and findings from the three studies in relationship to their implications for teacher educators, for pre- and in-service teachers, assessing conceptual change/understanding, and for conceptual change researchers. The limitations of the three studies are also discussed, followed by recommendations for future investigations in conceptual change research. Finally, the chapter ends with a brief summary and conclusion of the studies in their entirety.

Implications of the Studies

These studies afforded me opportunities to work with preschoolers, in-service early childhood teachers, college students, and the undergraduate chemistry department at The Ohio State University. The three studies have provided rich data that has created a unique space and opportunity to view conceptual change and understanding in cross-age populations, highlighting the complexities of teaching for conceptual change, of assessing conceptual change, and of conducting conceptual change research.
Teaching for Conceptual Change

Teachers must be aware of the original conceptions students hold, as these will influence the ways in which the students interact with new content (Hewson, 1992). We know it is not enough for teachers to merely acknowledge that students come to instruction with naïve conceptions; instead, teachers need to engage students and design instruction to facilitate student conceptual change (Hewson, 1981). In addition, instruction for conceptual change must not only promote the construction of new explanations and theories but also new ways of learning, reasoning, and thinking.

Each of the three studies conducted as part of this dissertation research hold implications for the future of science teacher education. Teachers need to be made aware of alternative conceptions and the role(s) these alternative conceptions will play into the ways scientific information is constructed in the classroom. By understanding what conceptual understanding is and where/how students construct knowledge, teachers can be more prepared to teach for restructuring alternative conceptions and conceptual understanding. A look into our college science classrooms (study three) holds implications for all university students including those who may one day be teachers of our young children. Looking into the alternative conceptions (a later study) may show that students in different majors generally have similar conceptions. If this was the case, we could see changes to the way students are grouped into their first year science classes at the university level, as it could alter instruction. Study two assesses the conceptual understanding of in-service teachers both pre and post PD; a possible interesting layering for a future study would be to interview such participants and speak with them in-depth.
about both their reasonings and their meta-cognitive awareness both pre and post PD. It would also be helpful to collect field notes of observations of the students’ engagements during the PD. Study one provides evidence for the starting point(s) of the learning trajectory of young students and astronomy concepts. It also provides evidence for the age appropriateness of science investigations at the preschool level, since science in preschool is often argued as not being age-appropriate. The descriptions of children’s understanding of the day and night cycles provided in this study may lead to more effective curriculum and teaching strategies for very young children. Since celestial objects appear in many books for young children and many young children are aware of these celestial objects, early childhood educators may assume that young children already have made connections between objects in the sky and the time of day of observation. However, findings of study one suggest that while young children understand what the sky and celestial objects, (sun, moon and stars) are, their understandings do not often reach much further than their own egocentric observations.

**Assessing for Conceptual Change and Understanding**

Assessment carries multiple meanings beyond generic formative and summative; assessment can mean assessing for change, assessing for understanding, assessing for different types or modalities of understanding, assessing initial conceptions, and assessing alternative conceptions.

Study three, an psychometric evaluation of the NSS-DI Eng instrument, was necessary in hopes to provide chemistry teachers and chemistry education researchers with an reliable instrument for assessing student conceptions of solution chemistry
concepts. Performing the statistical analysis of the NSS-DI in turn lead to better statistical measures being used for the data collected in studies one and two. These changes included selecting more appropriate statistical measures for study one by using non-parametric statistical analysis. Statistical measures can actually undermine results if the correct statistical methods are not employed.

Although the scope of study three was limited to a statistical analysis, the study itself will provide rich detail beyond the data reported here. The data from study three will provide evidence for the most common alternative conceptions among this population of college students enrolled in a first year chemistry class. From the collected data, correlations can be examined between overall scores and major/year/gender, and common alternative conceptions and major/year/gender. While the purpose of study three was to perform a psychometric evaluation of the reliability of the English version of the NSS-DI, the data collected will provide key evidence for future chemistry education research studies.

Assessment brings to mind labeling, grouping, identifying high and low students and can carry negative connotations. We cannot improve our practice without assessing where we are, where we need to be and the best ways to get there. Assessments within conceptual change research often seek to identify and label common misconceptions. The word “misconceptions” causes many people to wince as they envision it indicative of a deficit mindset. Throughout the course of this written document, purposefully the word “misconceptions” (unless used by the researchers cited or in the history of conceptual change) has been modified and referred to as “alternative conceptions”. I do not view
students’ naïve understandings as a deficit, instead, quite the opposite as it is an active process of the student trying to make meaning from the world around them. While alternative conceptions can pose as obstacles to instruction, these should not be viewed as problematic, rather to see them as exciting opportunities. Alternative conceptions provide windows into the thinking and accommodation processes that are happening within the mind of the student.

**Conceptual Change Framework for Research**

The field of conceptual change research is unique as it has researchers from two different fields feeding the literature base. On one side, the cognitive psychologists seeking to understand *how* conceptual change happens, and on the other, science education researchers seeking to answer *why* conceptual change occurs. Individually, these studies hold their own implications for the research base. Study one demonstrates generally successful conceptual change (both the how and the why) that takes place with young children through a play-based instructional sequence. The concepts presented were age-appropriate and were likewise presented in an age appropriate pedagogy.

Study two, reported gains, however the participant group demonstrated different characteristics than previous studies with in-service teachers. Since there are no other published studies with solely preschool teachers and science content and/or conceptual change there is an obvious call for more research on this group as a whole and specifically with science content. These findings could also point to teachers paying most attention to the content they are expected to teach in their classroom and just a few grades above. When the content gets “too far” removed from their grade level, do they
begin to ‘tune out’? This study has larger implications for science education researchers as to why this group saw lower gains than in previous studies with the broader grouping of early childhood teachers. Clearly, the results point to differences between this group and the larger group of early childhood/elementary teachers reported on in the extant literature. In looking at the PD, cognitive conflict was utilized, as it brought participants prior conceptions to mind, and attempted to make them dissatisfied and revise their conception to a more scientific understanding. These findings could indicate that this group may respond better to instruction that includes activities which resolve conflict.

**Study Limitations**

Studies always come with limitations; some are due to structural design limitations and others are due to the limitations we all have because of particular viewpoints and biases from our own worldviews. The limitations are briefly discussed in the body of each article, but warranted additional comments.

Whenever interviewing preschoolers, the distractions are plentiful. Limitations to the interview process itself were children being more interested in the video-recorder than the interview questions themselves. Understanding the language of very young children can also pose problems at times. During such times of incomprehensible speech, a researcher must go on with a blank answer for that item even though the participant was clearly trying to answer or communicate. Interviewing young children works best in an organized room, free from too many distractions (e.g. toys, balls, computers) and during any time other than recess or lunch.
It should always be noted when a member of the research team is also delivering content or instructing as part of the professional development. Participants naturally want to perform well for their teachers/instructors and may be hesitant to ask questions or speak up when they find the content unclear. This also makes it hard for the research team to fully understand the position of the teachers and their experience as a participant in the PD. The PD’s were scheduled on Saturdays and, although the teachers volunteered to participate, teachers do not always like to give up their limited free time to participate in PD.

Similar to teachers being ready for their own free time, college students are ready to run for the doors when class is over. In many of the sections where I collected data in during the fall of 2014, the instructors/GTAs allowed me access to the class at the beginning of the lab/class time. Other intro chemistry instructors from summer 2014 and fall 2014 wanted to administer the instrument at the end of class time. As there were no incentives to participate and it was not a requirement of their class, many students saw this as an opportunity to leave class early in lieu of participating in the data collection for the NSS-DI Eng. Participant numbers could have been boosted if the instrument was administered to all classes at the beginning of class time. If students had taken longer to think about their responses and reasonings, this might have also improved scores and responses. It is possible that students who took the instrument at the end of class were rushing simply so that they may leave class early.
All of these concerns and limitations are issues typical of educational research. While some of them are not preventable, some are and should be considered in future research study designs.

**Areas of Future Research**

The purpose of these studies was to examine either conceptual change and/or conceptual understanding with three different populations, two of which received instructional interventions and one group who was assessed for their initial conceptions prior to instruction. Data analysis confirms gains were seen across the groups that received the instructional interventions. Data from study three were used to evaluate the reliability of the NSS-DI Eng instrument. The data collected will also inform future studies as it shows student’s initial conceptions and reasonings prior to solution chemistry instruction. Collectively, these studies support creating experiences that encourage play in our youngest children’s schooling experiences, providing ongoing science oriented professional development experiences for all teachers, especially early childhood teachers, and for ongoing research in our college science classrooms to provide more effective teaching and learning experiences at the university level. An area for further research is to examine whether these findings with the young children assist in their building a more scientific mental model for the cause of the moon phases later in middle school than children who were not exposed to play-based instruction in their early childhood experience. Other areas include following the teachers after the professional development experiences to view the efficacy of their instruction a year (and subsequent years) out from the PD. Is the instruction changing, and if so, how? Are the children in
these classrooms more likely to provide scientific reasoning for how they know the sky is day or night than children not in a class with a teacher who has received space science PD? The data from the NSS-DI administration will lead to research revealing naïve conceptions of U.S. students enrolled in a first year chemistry class and will also be used in a cross-cultural comparison to Turkish students’ naïve conceptions.

**Conclusion**

A review of the literature on the current state of science education and conceptual change revealed recurring themes: 1. low teacher self-efficacy and preparation for teaching science within the early childhood group of teachers. 2. lack of age appropriate science experiences in preschool classrooms, and 3. alternative conceptions are common population-wide and can be difficult to change, even with instruction.

In order to move beyond this limiting and deficit reporting of our elementary and early childhood teachers, teacher education programs must provide teacher candidates with the skills and content necessary to feel confident in providing research-based science experiences for young children. Programs should embrace teaching methods that invite teacher candidates to participate in lessons and experiences as young children would and afterward engage in critical questioning of pedagogical choices in a manner that is student-centered and open to the increased diversity of today’s preK-12 classrooms. For in-service teachers, universities and teacher educators need to provide high-quality professional development experiences that are applicable to the locations and populations with whom the teachers work. The study with the preschool teachers raises new questions and possibilities for the separation of this group from the larger
elementary/early childhood group to advance opportunities that will be inclusive of both content and pedagogical knowledge, respectful of the multiple roles preschool teachers perform in the classrooms. Providing such experiences to pre-service and in-service teachers assists in the combatting of themes one and two, as stated above.

Alternative conceptions are widespread and can be difficult to change even with instruction. These findings are well-documented, yet the question still exists: how can we best promote conceptual understanding for all students? The good news in the literature base being so vast is there are so many researchers seeking their own lines of research to answer this very question. The bad news may be that all are so engrained in their own line of study that rarely do we have time to examine how these lines may complement each other and lead to a better understanding of conceptual understandings and what promotes conceptual change. While the field is dense with researchers, the questions are big and the demand real. The field has the capacity to bring about better science experiences for all students and better interpretations of the learning process for science education researchers.
References


References


Cheng, M., & Gilbert, J.K. (2009). Towards a better utilization of diagram in research into the use of representative levels in chemical education. In J.K. Gilbert & D.F. Treagust (Eds.), *Multiple representations in chemical education* (pp. 55–73). Dordrecht: Springer.


Merriam, S. B. (1998). *Qualitative Research and Case Study Applications in Education. Revised and Expanded from" Case Study Research in Education."*: ERIC.


National Association for the Education of Young Children [NAEYC]. (2002). *Position statement: Developmentally appropriate practice in early childhood programs serving children from birth through age 8*. 152


conceptual change: Preservice elementary teachers' conceptions of moon phases. 


## Appendix A: Overview of the Instructional Sequence for Day/Night Concepts

<table>
<thead>
<tr>
<th>Day</th>
<th>Topic</th>
<th>Activities</th>
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| 1   | Introduce daytime play | • Introduced diurnal animals by asking what time of day the animals could be observed  
• Introduced campsite in the dramatic play area  
• Responses from children’s play = fishing, hiking, looking for animals  
• Children sang “going on a bear hunt” as they marched to the campsite  
• Made a pretend campfire and used cooking utensils  
• Children acted out all the things they could do for camping in the day time (ie. Collecting berries, using blocks to fish, cooking on campfire, washing dishes in a stream, and singing around the campfire) |
| 2   | Intentional Instruction/Day time sky | • Read books (National Geographic Big idea Day and Night book (Halko, 2011a) and Day/Night on a Farm (Halko, 2011c) (day parts ONLY)  
• Focused the children’s attention on color and things you can see in the sky (sun, moon), this was done as whole group in circle area  
• In small groups, children were taken outside to make observations about the sky  
• Asked about the color of the sky, what they could see. Drawing attn. to the sun and clouds  
• Looked for the moon  
• While outside, they drew what they saw in the sky using clipboards with blue paper, white pencils and yellow crayons  
• They came back inside and compared their drawings to a day sky being projected on the wall via Starry Night software by Imaginova  
• Compared color of day sky and objects (sun and clouds) in the sky, and if the moon was visible today  
• Still in small group, re-read Day and Night on a Farm and compared the pictures to their observations  
• Repeated in groups |
| 3   | Play/Night time | • Introduced nighttime sounds and animals  
• Dramatic play center featured camping at night  
• One netbook and the projector projected the night sky on the wall in the ‘camping’ area  
• The teachers also turned the lights off during free-choice to simulate a night-time experience |
| 4   | Intentional Instruction/Night Time sky | • Teacher read from the big book on Day and Night (Halko, 2011a). (in large group)  
• She shared the night stars and moon pages in the book  
• She also read from the Day and Night on a Farm (Halko, 2011c)book about night only  
• Following, in small group, the children observed a projected image of the night |
### Day and Night Play

- Diurnal and nocturnal animals were placed in the centers together
  - Conversations heard with children around which animals would “play” together or “be friends” based on the time of day/night that they would be awake. For example, in one child created scenario, the possum was not friends with the robin as they would have no interactions during each of their typical days.
- The campsite was still in the dramatic play area
  - Changes in the materials included day and night materials both being out (e.g. flashlights for night and backpacks for day hikes)
- Children acted out different activities around dramatic and/or imaginative play around the room (e.g. fishing, acting out stories with animals, 'sleeping’ in sleeping bags, singing camp songs and or storytelling)

### Instruction Comparing day and night skies

- All of the day and night materials were available at the centers within the classroom on the day of intentional instruction
- In large group:
  - Read day and night in the woods
  - Children’s attention was on the different colors of sky (day and night)
  - And when you could see sun, moon and stars in the sky
- Class used a large chart for placing colors and objects in either day or night categories
- In small groups:
  - Students constructed their own individual charts
  - Colors were introduced first and the students selected which color was representative for a day sky and which color was representative of a night sky
  - Students were also given pictures of objects in the sky (sun, moon, and stars) and asked when these objects could be seen in the sky. Students placed the sun and moon in the day sky category while placing the moon and stars in the night sky category. Attention was drawn to the moon be observable in both day and night skies
Appendix B: Interview Protocol for Children (Objects in the sky)

Comparing day and night

• Look at the sky from the window right now and tell me, do you see a day sky or a night sky?
• How can you tell it is day (or night)?
• What color is the sky now?
• What things can you see in the day sky?
• What color is the night sky?
• What things can you see in the night sky?

Observation time

• When can you see the moon?
  o Can you see the moon during the daytime/ at nighttime?
• When can you see the stars?
  o Can you see the stars at daytime/nighttime?
• When can you see the sun?
  o Can you see the sun at daytime/nighttime?

Shapes

• Provide wooden geometric blocks of different shapes (a cube, a cylinder, a pyramid, a hemisphere, a disc and two spheres of different sizes).
• Ask children to choose three blocks each that look like the shapes of the sun, the moon, and a star respectively.
• Here is a box of various shapes. Would you select a shape that looks like the shape of the Sun?
• Why do you think this is a good shape for the sun?
  o Is the sun always the shape that you selected? Does it change shape?
• Now please select a shape that looks like the shape of the Moon?
• Why do you think this is a good shape for the Moon?
  o Is the Moon always the shape that you selected? Does it change shape?
  o What other shapes does the moon have?
  o Have you ever seen the moon look like any of these photographs? (Show
    moon phases picture)
  o Which shapes of the moon have you seen before? Show me with your finger.
• This time would you select a shape that looks like the shape of the stars?
• Why do you think this is a good shape for the Stars?
  Are the stars always the shape that you selected? Do they change shape?